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Development of a sampling system and characterization of stormwater runoff from a small urban area

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DEVELOPMENT OF A SAMPLING SYSTEM AND CHARACTERIZATION OF STORMWATER RUNOFF FROM A SMALL URBAN AREA

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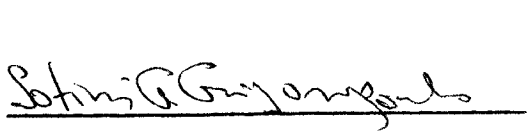

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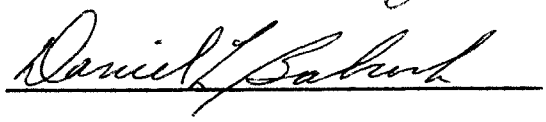

ABSTRACT

Increasing urbanization and the demand for high quality water have directed attention to the problem of combined sewer overflows, while recent research has demonstrated that stormwater alone, without the influence of sanitary sewage, carries a significant pollutional load. The purpose of this investigation was to determine the quality and pollutional contribution of stormwater runoff from a small urban area, with specific emphasis on the development of a suitable sampling and flow recording system, the characterization of runoff and the correlation of runoff quality with local environmental factors and storm characteristics.

The system developed consisted of an automatic sampler capable of taking a series of stormwater samples, each representing a runoff period varying from 5 min to 2 hr in duration, a flow recorder, and the necessary ancillary equipment to permit automatic operation. Runoff from 3 test watersheds in the Rolla area during 10 precipitation events over a 6-month period was sampled and characterized in the laboratory using physical, chemical and bacteriological determinations.

The characteristics of the runoff from the small urban area were similar to those reported for runoff from large metropolitan areas. The time since the beginning of the runoff event, the length of the antecedent dry period, the average intensity of precipitation and the basin slope were found to have an effect on runoff quality.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

Significant changes in the distribution of the population in the United States are taking place, and it is expected that over 90 percent of the people will be residing in urban areas by the end of the century (1, p.24). Successful urban existence depends on a safe and livable environment, 3 essentials of which are said to be clean air, clean land and clean water (2, p.11). Natural pollutional conditions of course do exist. Precipitation cleans the air by washing out contaminants, and water flowing over the land as runoff picks up additional soluble and insoluble materials on its way to a watercourse. The urban environment intensifies these pollutional conditions. The urban atmosphere has more diverse substances to contribute to precipitation, and urban drainage contains a far greater quantity of pollutants. Roads, streets, sidewalks, roofs, parking lots, shopping centers and other appurtenances of urban living decrease the pervious area available for the runoff to percolate into the ground, thereby greatly increasing the rate and quantity of runoff and consequently scour pollution. In addition, industrial and domestic wastewaters constitute a major source of pollutants in the urban environment (2, p.11).

Efforts are underway to eliminate pollution from the obvious sources of discharge of untreated or undertreated industrial and municipal wastes. With the reduction in the concentration of pollutants in these discharges, other less obvious sources of pollution take on increased significance. Among the latter sources of pollution are overflows of sewage and industrial wastes mixed with stormwater in combined sewers, and separate storm sewer discharges during periods of precipitation runoff or thaw runoff (2, p.12).

The development of sewer systems has followed a general pattern throughout the years. Communities were usually established by the side of a river because it could furnish a source of power, transportation and water supply. Stormwater collection and diversion was one of the early concerns of these communities. Discharge, via ditches and later closed sewers, directly to the waterway was the usual method of dealing with this problem. With the advent of public water supplies and the adoption of the principle of water carriage for removing household wastes, domestic wastewater disposal became a problem. Existing storm sewers were conveniently used to carry the domestic sewage to the stream where it was discharged without treatment; however, increased population density and waste volumes, and a better knowledge of the effect of untreated wastewater on the streams made the need for treatment apparent. It was consequently necessary to intercept the numerous sewers which were discharging directly to the waterway with an interceptor, and in order to keep the system within economical and practical limits it was required to allow excess stormwater and sanitary sewage to overflow directly to the stream. Although this procedure resulted in the discharge of untreated wastes during periods of overflow, it was thought that the stormwater in the sewer and the water in the stream would provide sufficient dilution of the raw sewage to render it unobjectionable.

Today it is no longer considered desirable to bypass combined sewage directly to the waterway. Increased urbanization and the demand for high quality water have intensified the requirement of eliminating all sources of water pollution (3), and combined sewer overflows are now receiving considerable attention (2, p.12). Because it had been assumed that little or no problem would accrue from direct discharge of

separated stormwater, replacement of combined sewers with separate storm and sanitary sewer systems was proposed as an effective means of reducing pollution by combined sewer overflows. The cost of separation (for the nation as a whole) was estimated by the American Public Works Association (APWA) in 1967 at a staggering $48 bil (4). This value updated to 1971 costs would be approximately $64.5 bil.* In addition to the high cost of sewer separation, recent research studies (4)(7)(8) have demonstrated that stormwater alone, without the influence of sanitary sewage, carries a significant pollutional load and cannot be neglected when considering urban source waste loading.

The quality of urban stormwater runoff has been investigated in several areas of this country and in a number of other countries as well. Although many of the early studies involved a limited number of samples which were examined for relatively few characteristics, more recent work, particularly that by Weibel, et al. (7) of a site in metropolitan Cincinnati and by Cleveland, et al. (8) of 15 sites in Tulsa, have been thorough.

A report prepared by the American Society of Civil Engineers (ASCE) (1) for the US Geological Survey has proposed a national program of urban stormwater drainage research. This study recommended that research begin with at least 1 or 2 rather complete pilot installations, established in metropolitan regions which are as climatologically disparate as possible, to evaluate precipitation, runoff and water quality from urban areas. The central goal of this program according to ASCE should

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*This value was determined using the ratio of the 1971 avg sewer construction cost national index of 167.18 (5) to the 1967 avg index of 124.45 (6).

be to obtain the highest degree of transferability of data from one metropolitan area to another. This objective would be accomplished once mathematical modeling parameters have been generalized for a sufficient number of metropolitan regions so that interpolation or extrapolation of data could be made satisfactorily for all other metropolitan regions. If transferability were not achieved with the initial pilot installations, the extent of further regional sampling required should at least be indicated.

Efforts to develop stormwater runoff models have been recently reported in the literature. Cleveland, et al. (8) have used data from their studies in Tulsa to develop a set of regression equations, while Lager, et al. (9) have written a generalized computer program and used existing data to predict quality and discharge characteristics. Further work is, however, necessary in order to achieve transferability of data. Cleveland and co-workers did not apply their parameters to other areas, while Lager and associates did not give specific information on the degree to which their program was able to predict runoff characteristics other than stating that the results were acceptable.

Previous studies of urban stormwater runoff quality have centered for the most part around the larger metropolitan areas, even though many of the watersheds involved were physically small. With the anticipated increase in urbanization and development of exurban communities, small urban areas will continue to grow throughout the country, and their contribution to the stormwater problem cannot be overlooked.

Study of storm runoff from a small urban area should provide information on the pollutional contribution of these areas and the

degree of similarity of the quality of the runoff from the small and large metropolitan areas. In addition, such a study should provide a means for evaluating the transferability of data and models between small and large metropolitan areas.

The study of the quality of stormwater runoff from a small urban area should be as thorough as possible and should deal, at least initially, with as many physical, chemical and bacteriological characteristics as possible. This is in line with the ASCE recommendation (1, p.70) that "...no quality parameter of potential significance should be omitted at the beginning of the national information program, and parameters should be dropped only when their relevance is proven to be minor." Related information, including streamflow and precipitation data, should be incorporated in the study. Use of automatic sampling equipment would greatly facilitate the work. The ASCE study (1, p.93) has recommended automatic sampling using a battery of bottles, and onsite recording of temperature, dissolved oxygen, pH and conductivity using electrochemical sensors; however, as the report pointed out, a proper bottle sampler was not available.

The overall objective of this investigation was to determine the quality and pollutional contribution of stormwater runoff from a small urban area. Specific objectives included: (a) the development of a suitable sampling and flow recording system, (b) the characterization of runoff and (c) the correlation of runoff quality with appropriate local environmental factors and storm characteristics. Emphasis in this phase of the project has been placed on the development, construction, installation and field evaluation of the necessary automatic sampling and flow recording equipment.

Rolla, a growing city of about 13,000 located in south central Missouri at the edge of the Ozarks region, was selected as the site of the study. It is located in the Mississippi Valley near the center of the contiguous United States and in close proximity to rural areas and streams used extensively for recreation and fishing. Three watersheds varying in size, land use, topography and drainage features were chosen, and suitable locations for installation of sampling and flow recording equipment were selected. An automatic sequential sampling system was developed, and samplers were constructed and installed at the 3 locations together with continous streamflow recording gages. Precipitation data were obtained from the weather station located on the University of Missouri-Rolla (UMR) campus. Runoff from several storms during a 6-month period (February to August 1967) was sampled and characterized in the laboratory using physical, chemical and bacteriological analyses.

II. REVIEW OF LITERATURE

The purpose of this literature review is to present information on previous work undertaken to characterize stormwater runoff from urban areas; the review does not include studies conducted on overflow from combined sewers, except when they were concerned with the quality of sewage-free stormwater. Information on sampling and flow measuring systems has not been included in this section because little of the material available in the literature was of direct application to the present investigation. Appropriate references are discussed in Chapter IV "Design and Construction of Sampling and Flow Recording System."

A. SUMMARY OF PREVIOUS STUDIES

A summary of the results obtained by other investigators in characterizing urban stormwater runoff is presented in Table I. Tabular form has been employed to minimize repetition, to best show the various parameters determined in the different studies and to permit ready reference to the material for discussion.

The studies summarized in this table cover a span of almost 40 yr, from 1932 (line 13) to 1971 (line 18). Little information is available in the literature on long term changes in stormwater runoff quality. Studies conducted by the Los Angeles Flood Control District (line 13) have demonstrated a steady increase in BOD and inconclusive trends for the other parameters measured over the 30-yr period evaluated. On the other hand, Pravoshinskiy and Gatillo (26) comparing data they had obtained at Minsk (line 15) with findings of previous work done at Moscow (Vasileostrosk District) in 1936 and Leningrad in 1948-50 (line 4) found that substantial agreement existed in values obtained over a 30-yr period.

TABLE I. CHARACTERISTICS OF URBAN STORMWATER RUNOFF-SUMMARY OF PREVIOUS STUDIES

LINE	AUTHOR	LOCATION AND DATE	VALUE	PHYSICAL PARAMETERS									BACTERIOLOGICAL PARAMETERS			REF.	Line
				TURBIDITY	COLOR	TOTAL RESIDUE: TOTAL	TOTAL RESIDUE: VOLATILE	TOTAL RESIDUE: FIXED	DISSOLVED MATTER	SUSPENDED MATTER: TOTAL	SUSPENDED MATTER: VOLATILE	SAND	OIL AND GREASE	COLIFORMS: TOTAL	COLIFORMS: FECAL	FECAL STREP: TOCOCCUS		
				units		mg/l								MPN/100 ml				
1	Palmer	Downtown Detroit, MI March 22, 1949	Range			310-914	136-414							25,000-930,000			10	1
		July 13 & 26, September 12 & 19, 1960	Range							102-Avg 213	38-Avg 121			2,300-430,000			11	
2	Akerlindh	Stockholm, Sweden	Range			30-3,000		2,420 (High)						40-200,000			7,12	2
			Median			300								4,000				
3	Wilkinson	Oxney, England Housing estate, 1954	High							2,045							7,13	3
4	Schigorin	Vasileostrosk, USSR 1936	Range							1,000-3,500							7,14 15	4
		Leningrad, USSR 1948-50	Avg							14,541							7,14 16	
5	Guzman	Caribbean, Rain catchment areas, 1959	High		100												17	5
6	Welsch	Nassau County, NY 1960	Range						132-218								18	6
7	Guy & Ferguson	Lake Barcroft, VA 1938-57	Range			3,000-86,000											19	7
		Kensington, MD 1959-60	Range			680-105,000												
8	Sylvester & Anderson	Seattle, WA Green Lake, 1959-60	Range	125-475*	55-180*								43-110*	2,910-5,780*			20	8
9	Stander	Pretoria, South Africa Residential, school, park & sportsgrounds, 1961	Avg						228					240,000			7,21	9
		Business and flat area, 1961	Avg						154					230,000				
10	Weibel, et al.	Cincinnati, OH July 1962-September 1963 (Jan & Feb not included)	Range	30-1,000	10-380					5-1,200	1-290			2,900** 58,000# 460,000##	500** 10,900# 76,000##	4,900** 20,500# 110,000##	7,22	10
			Mean	170	81					227	53							
11	Chanin	Oakland, CA East Bay Metropolitan Utility District, Storm sewer flows, undated	Range		2-162					16-4,400		7-868	2-162	4-70,000			3	11
			Avg		32	1,401	168			613		158	32	11,800				
		Creek samples from areas not receiving wastewater undated	Range		0-100					780-1,620		193-1,074	0-100	130-62,000				
			Avg		25	1,401	158			1,176		560	65	13,800				
12	Greeley, et al.	Washington, DC 1957	Range							26-36,250							3	12
			Avg							2,100								
13	Anonymous	Los Angeles County, CA Los Angeles Flood Control District 1932-34 1957-58 1962-63	Avg							7,330 1,534 2,909							3	13
14	Burm & Vaughan Benzie & Courchaine	Ann Arbor, MI 1963-64	Range							900-2,062				26,500-17,500,000	7,500-1,115,000	13,800-730,000	23 24	14
			Mean							1,280								
	Burm, et al.	1965	High							11,900	570						25	
			Mean							2,080	218							
15	Pravoshinskiy & Catillo	Minsk, USSR Rainfall runoff 1964-66	Range							450-5,000 (15-60)+							26 27 28	15
		Street washing 1964-66	Range							30-8,300 (12-75)+								
		Snow melt 1964-66	Range							574-4,950 (10-65)+			about 200					
16	Cleveland	Tulsa, OK 15 test sites 1968-69	Range			199-2242*			89-400*	84-2,052*	24-296*			2,100** 57,000# 1,140,000##	2** 30# 30,000##	2** 5,000# 167,000##	8	16
17	DePillipi & Shih	Washington, DC April-September 1969	Range			338-14,600	12-1,004			130-11,280	0-880			120,000-3,200,000	40,000-1,300,000	3,000-60,000	29	17
			Mean			2,166	302			1,697	145			600,000	310,000	21,000		
18	Mische & Dharmadhikah	Tucson, AZ 3 watersheds 1971	1						189	777				5,900,000	1,030,000	130,000	30	18
			Avg 2	624					173	1,394				42	82	727		
			3	1,059 1,734					264	1,876				42	19	6		

*Range of test site avg.

**,#,##Counts exceeded in portion of samples, as follows: **90%, #50%, ##10%.

+Organic matter.

TABLE I (Continued). CHARACTERISTICS OF URBAN STORMWATER RUNOFF-SUMMARY OF PREVIOUS STUDIES

LINE	AUTHORS	LOCATION AND DATE	VALUE	CHEMICAL PARAMETERS															REF.	LINE
				pH	BOD_5	COD	DISSOLVED OXYGEN	PHOSPHORUS		NITROGEN				TOTAL HARDNESS	ALKALINITY	IRON	CHLORIDE	PHENOLS		
								SOLUBLE	TOTAL	AMMONIA	ORGANIC	NITRITE	NITRATE							
				units	mg/l			mg/l as PO_4		mg/l N				mg/l as $CaCO_3$			mg/l			
1	Palmer	Downtown Detroit, MI March 22, 1949	Range		96-234														10	1
		July 13 & 26, September 12 & 19, 1960	Range																11	
2	Akerlindh	Stockholm, Sweden	Range		80 High	18-3,100													7,12	2
			Median		17	188														
3	Wilkinson	Oxney, England Housing estate, 1954	High		100														7,13	3
4	Schigorin	Vasileostrosk, USSR 1936	Range																7,14 15	4
		Leningrad, USSR 1948-50	Avg		36														7,14 16	
5	Guzman	Caribbean, Rain catchment areas, 1959	High																17	5
6	Welsch	Nassau County, NY 1960	Range													0.1-0.8	2-4	.01 (High)	18	6
7	Guy & Ferguson	Lake Barcroft, VA 1938-57	Range																19	7
		Kensington, MD 1959-60	Range																	
8	Sylvester & Anderson	Seattle, WA Green Lake, 1959-60	Range					0.04-0.085*	0.160-0.305*		0.70-4.25*		0.35-0.95*						20	8
9	Stander	Pretoria, South Africa Residential, school, park & sportsgrounds, 1961	Avg		30	29					5.4								7,21	9
		Business and flat area, 1961	Avg		34	28					3.5									
10	Weibel, et al.	Cincinnati, OH July 1962-September 1963 (Jan & Feb not included)	Range	5.3-8.7	2-84	20-610			0.07-4.3	0.1-1.9	0.2-4.8	0.02-0.2	0.1-1.5	29-240	10-210		3-35		7,22	10
			Mean	7.5	19	99			1.1	0.6	1.7	0.05	0.4	78	59		12			
11	Chanin	Oakland, CA East Bay Metropolitan Utility District Storm sewer flows, undate	Range	6.3-7.8	3-≈700		0-13.2										300-10,260		3	11
			Avg	6.9	87		7.3										5,100			
		Creek samples from areas not receiving wastewater, undated	Range		< 5-35		2.8-8.2													
			Avg		17		4.8										540			
12	Greeley, et al.	Washington, DC 1957	Range		6-625												11-160		3	12
			Avg		126												42			
13	Anonymous	Los Angeles County, CA Los Angeles Flood Control District 1932-34 1957-58 1962-63	Avg		6.9 8.2 16.1		6.4 8.0 7.5										20.4 ---- 19.9		3	13
14	Burm & Vaughan Benzie & Courchaine	Ann Arbor, MI 1963-64	Range						1.6-9.5	0.29-0.68	0-0.52							0.001-0.011	23 24	14
			Mean						2.9	0.48	0.36									
	Burm, et al.	1965	High		62			3.4	16.4	2.0	4.0		3.6					0.070	25	
			Mean		28			0.8	5.0	1.0	1.0		1.5					0.016		
15	Pravoshinskiy & Gatillo	Minsk, USSR Rainfall runoff 1964-66	Range		12.5-145												6.4-32		26	15
		Street washing 1964-66	Range		6.1-223												11.0-16.7		27	
		Snow melt 1964-66	Range		5-105												6.4-58		28	
16	Cleveland, et al	Tulsa, OK 15 test sites 1968-69	Range	6.8-8.4*	1-39*	12-105*		0-15.1*			0-5.32*						2-64*		8	16
17	DePillipi & Shih	Washington, DC April-September 1969	Range	7.2-6.0	3-90	29-1,514			0.2-4.5										29	17
			Mean	6.5	19	335			1.3											
18	Mische & Dharmadhikari	Tucson, AZ 3 watersheds 1971	1			230													30	18
			Avg 2			185														
			3			497														

*Range of test site avg.
**One sample on June 8, 1969.

The work represented in Table I varied greatly in the extent and depth of investigation. Some studies were minimal (lines 1, 5, 6, 11, 12 and 13) in that only a few manual grab samples were utilized in characterizing runoff. This was often done as part of a study of a different but related area, such as the problem of combined sewer overflow (line 1), drinking water supply (line 5), or groundwater recharge (line 6). Little detailed information was available for 5 of the investigations (lines 2, 3, 4, 9 and 15), and it was difficult to determine exactly what sampling techniques were used, or how the data were obtained.

One study (line 7) might be classed as a special investigation. The data reported were obtained in part by measurement (the method of measurement was not given), and in part by calculation using runoff quantity and sediment build-up information.

Two investigations (lines 8 and 18) were more complete although both utilized manual sampling techniques. The characterization of urban stormwater runoff was only one aspect of a larger project dealing with the eutrophication of a lake in one of these studies (line 8), while it was the main objective of the other study (line 18). Four studies (lines 10, 14, 16 and 17) employed automatic samplers in order to perform a more extensive characterization of urban runoff, and these are discussed in more detail in the following pages.

1. The Cincinnati Study

Weibel, et al. (line 10) studied urban stormwater runoff from a 27-acre (11-ha) residential and light commercial area in the Mt. Washington section of Cincinnati, which was provided with separate sewers. Precipitation was recorded on a weighing-type continuous

recording rain gage with a 24-hr chart, and stormwater flows were measured using a continuous water level recorder with a 24-hr chart and a 4-ft (1.2-m) rectangular weir installed in a ravine. Runoff samples were collected using an automatic sampler equipped with a pump which was turned on by a float-activated switch at the onset of flow. Rainfall samples were collected in a pair of large shallow trays. The water level recorder chart was used to select samples for analysis which were analyzed individually; the results were then used to compute composite concentrations and loads.

2. The Ann Arbor Study

Discharges from separate storm sewers in an Ann Arbor area and from combined sewers in a Detroit area were characterized by Burm and co-workers and Benzie and Courchaine (line 14) in two different time periods. The earlier study dealt with the bacteriological quality of the discharges, while the latter study was concerned with chemical and physical parameters. The district drained by the separate storm sewers had an area of 3,800 acres (1,540 ha) most of which was within the city of Ann Arbor, although there was a sizeable amount of rural drainage. Precipitation was measured on a single recording gage located within the district. Grab samples were taken automatically every 5 min; this short time interval was used because of the rapidly rising and falling hydrograph. The sampler lines were flushed automatically for 90 sec before the first sample was taken.

3. The Tulsa Study

Cleveland and co-workers (line 16) investigated stormwater runoff from 15 sites in the Tulsa area in an attempt to relate stormwater pollution to urban land activity. This work was undertaken in an

effort to develop a method of analysis which would enable the city planner and the engineer to assess the quality as well as the quantity of stormwater runoff by examining land activities, environmental factors and precipitation. An inclined sequential sampler activated by an increase in flow was used to take samples automatically. The samples were analyzed extensively and the water quality data obtained at the various sites were used to formulate a series of regression equations for different environmental conditions.

4. The Washington Study

DeFillipi and Shih (line 17) sampled combined sewer flows in 2 sewer districts and separate storm sewer flows in 1 sewer district in Washington from April through September 1969. The drainage areas ranged in size from 110 acres (44.5 ha) to 265 acres (107 ha). Automatic, instantaneous grab samples were taken at 5 or 10-min intervals during the course of the storm. A pump mounted in the sewer continuously raised water from the sewer to an overflow tank from which evacuated bottles drew samples at the preset intervals. Flow was measured by releasing lithium chloride at a known rate into a manhole upstream from the sampling station, and the rate of flow in the sewer was calculated from the lithium concentration in the samples. Ten storms were sampled in the separate sewer system. The most significant operational difficulties cited by DeFillipi and Shih related to pumping wastewater from the sewer. Pump stoppages from low flows, clogging by debris and physical damage from heavy objects washing downstream were also mentioned.

B. FACTORS AFFECTING RUNOFF QUALITY

1. Time

The variation of water quality with time is one of the most frequently discussed phenomena of urban stormwater runoff. The condition when water quality improves with time during runoff has been described in the literature as the "first flush-off effect." Palmer (11) has reported that in some cases runoff quality did improve with time, while in other cases it deteriorated, and in still other cases there was no apparent pattern.

The first flush-off effect has been shown for BOD (biochemical oxygen demand) in both Los Angeles (3) and Ann Arbor (25). In Los Angeles, BOD concentrations determined early in a storm were as high as 70 mg/1, but decreased as the storm progressed, finally leveling off in the neighborhood of 10 to 20 mg/1. In Ann Arbor, BOD was found to decrease by 30 percent from 47 to 32 mg/1 after the initial 4-min sampling interval. Pollutant concentrations were also found to decrease with time following the start of a precipitation event. In Washington (29) this effect was noted for all characteristics determined and for all storms examined. Concentrations of constituents were found to increase with discharge during the first flushing period.

The first flush-off effect was not observed in Detroit (25) combined sewer discharges relative to the SS (suspended solids) concentration, and in Oxney (7)(13), the first runoff was not found to be much more polluting than subsequent flows, except after long antecedent dry periods. Two possible sources of first flush-off, or shock pollution, in Chicago were reported by an APWA study (2) to be street litter and catch basin contents.

The length of the antecedent dry period was observed to be a factor in the quality of runoff in Oxney (7)(13), Seattle (20), Tulsa (8) and Washington (29). In Oxney, BOD values tended to increase with an increase in the length of the preceding dry weather period up to a maximum of 8 to 10 days; after this period, little additional change was noted. In Seattle, the highest concentrations of contaminants occurred when the antecedent rainfall had been low, as can be seen in the following comparison of data obtained from the analysis of arterial and residential street runoff.

	Rainfall During Wk Prior to Sampling, in.			
	0.0		0.42	0.66
	Arterial	Residential	Arterial	Residential
Turbidity, units	475	200	125	125
Color, units	180	80	85	55
Total Organic Nitrogen, mg/1 N	4.25	2.10	0.70	1.22
Nitrate Nitrogen, mg/1 N	0.95	0.50	0.35	0.44
Total Phosphorus, mg/1 P	0.22	0.30	0.19	0.16
Oil, mg/1	110	68	47	43
Coliforms, MPN/100 ml	2,910	5,780	4,470	4,460

In Tulsa, where regression analysis was used to develop models for the prediction of runoff quality, the concentration of pollutants was reported to decrease both with the time elapsed since the antecedent rainfall event and the time since the start of a given event. The length of the dry weather period between storms was found to influence the concentration of material carried in the initial flush of storm runoff in Washington; however, wind direction and velocity as related to pollution sources were reported to be potentially more important than the number of days of dry weather preceding the storm.

Differences in the effect of the season of the year were reported in several studies. In Tulsa (8) the season producing the greatest amount of runoff (March through May) produced the greatest amount of

pollutants. This was attributed to a higher runoff coefficient during this period which resulted in 50 percent of the annual runoff being produced in the 3-month period from 28 percent of the annual average rainfall. In Cincinnati (7), however, no pronounced change in runoff characteristics was found from season to season with the exception of BOD, which varied somewhat erratically with the season. In Ann Arbor, chemical parameters (25) were found to be reasonably constant throughout the year, but coliform levels (24) declined in winter and early spring from the levels found during warmer periods. Seasonal variations in bacterial densities have also been reported by Geldrich, et al. (31). Total coliform, fecal coliform and fecal streptococcus densities were found to be higher in the autumn in a business district stormwater runoff and urban street gutters. Runoff from a wooded hillside contained higher total coliform densities in the autumn, and higher fecal coliform and fecal streptococcus concentrations in the summer. Bacterial survival studies in stormwater by Geldrich and co-workers using selected enteric bacteria have demonstrated that the organisms persisted at higher levels at 10° C (winter conditions) than at 20° C (summer conditions). Studies by the Los Angeles Flood Control District (3) have indicated that the first storm of the season was responsible for higher coliform counts than were storms later in the season. This was attributed to accumulated organic dirt rich in coliforms which was washed into the receiving waters by the first storm.

2. Basin Slope

The slope of the drainage basin has been reported to affect runoff quality in two instances. Burm, et al. (25) in a parallel study of separate sewers in Ann Arbor and combined sewers in Detroit

determined higher values for all solids parameters in the separate sewers and attributed this to greater erosion and scouring on the Ann Arbor watershed due to its hilliness. Guy and Ferguson (19), comparing data obtained at Kensington and the Lake Barcroft area, reported higher sediment loadings at Kensington and attributed their findings in part to the greater slope of streams in that drainage basin which insured greater transport efficiency.

3. Land Use

Land use activities have a bearing on runoff quality. In Tulsa (8), high daily usage of a commercial and industrial area resulted in a decrease in the amount of pollution produced per unit area because of the better maintenance afforded the area. In residential areas the pollution produced per unit area increased with the population density and/or the number of developed parcels. Land surface developments having the strongest effect on the concentration of pollutants in stormwater were environmental conditions, geomorphic conditions affecting drainage and degree of development. Street refuse (litter) was identified by the APWA study (2) in Chicago to be a potential source of water pollution when it came in contact with stormwater or melt water runoff. The amount and nature of street refuse in turn varied with land use, population, traffic flow and other factors.

The type of street paving used in an area may also affect runoff quality. Schigorin (14)(15)(16) has reported marked fluctuations in the concentration of suspended solids in the runoff from streets in Leningrad and Moscow and has attributed these to the varying degree of dirtiness of different streets. Runoff from cobbled streets with comparatively light traffic was much less polluted than runoff from

asphalt streets with heavy traffic. Welsch (18) measured 0.01 mg/l phenol in stormwater from a groundwater recharge basin and suggested that the phenols probably originated from stormwater running off street pavements surfaced with bituminous tar material; however, no phenol was found where asphaltic pavement had been used. Guzman (17) has reported that pickup of asphaltic contaminants in water running off paved catchment areas in the Caribbean could produce color as high as 100 units.

Residential construction on a watershed can be expected to increase the concentration of solids in the runoff while the work is in progress. Guy and Ferguson (19) conducted approximately 100 sediment measurements in storm runoff from a 58-acre (23.5-ha) drainage basin at Kensington during the period of April 1959 to October 1960, when construction of streets and houses resulted in the exposure of 2 to 10 acres (0.8 to 4.0 ha) of subsoil. The concentration of sediment during this period was found to range from 105,000 mg/l during an intense thunderstorm when approximately 8.7 acres (3.5 ha) were exposed, to 680 mg/l during a slow, steady rain after most construction had been completed. These authors also reported that the average rate of sediment accumulation in Lake Barcroft was 3.68 acre-ft/yr (4,550 cu m/yr) prior to 1938, and 10.41 acre-ft/yr (12,880 cu m/yr) in the interval between 1938 and 1957. This increase was attributed to residential construction on the watershed. Between 1938 and 1957, 68 percent, or 9.5 sq miles (24.6 sq km), of the basin was urbanized. Each sq mile (2.40 sq km) passing through the construction cycle of clearing, grading, building and seeding resulted in an accumulation of approximately 19 acre-ft (23,400 cu m) of sediment in the reservoir. On the basis of

sediment accumulation from 1938 to 1957 and the mean annual runoff into the lake, 25 percent of which was assumed to be storm flow, Guy and Ferguson calculated that the sediment carried in the storm flow would have had an average concentration of 3,000 mg/1. If 1 sq mile (2.59 sq km) of construction were completed in 1 yr and the sediment generated were carried in the mean annual runoff, the concentration in the storm flow would have been approximately 86,000 mg/1. After construction has been completed, the sediment load may be expected to decrease significantly. According to Guy and Ferguson (19) the normal sediment load of storm flow in streams draining urban and suburban areas would be on the order of 200 to 300 tons/sq mile/yr (70 to 105 metric tons/sq km/yr), as opposed to 25,000 to 50,000 tons/sq mile/yr (8,750 to 17,500 metric tons/sq km/yr) during construction.

C. QUALITY OF RAINFALL

Because runoff begins as rainfall, the quality of rainfall must also be taken into consideration. In connection with stormwater runoff studies, Weibel, et al. (22) have characterized rainfall collected in large wooden trays lined with aluminum foil in the Cincinnati area and in a rural Ohio area near Coshocton. Average concentrations for several parameters were as follows:

	Cincinnati	Coshocton
SS, mg/1	13.0	11.7
COD, mg/1	16.0	9.0
Total nitrogen (sum of NH_3, NO_2, NO_3, organic), mg/1 N	1.27	1.17
Inorganic nitrogen (sum of NH_3, NO_2, and NO_3), mg/1 N	0.69	0.86
Hydrolyzable phosphate, mg/1 PO_4	0.24	0.08
Organic chloride, mg/1	0.28	0.22

III. AREA OF STUDY

A. GENERAL DESCRIPTION

The study was conducted in Rolla, MO. A small city of 13,245 (1970 census), Rolla is a growing community (19 percent increase in population from 1960 to 1970) (32) with an economy based on agriculture, county, state and federal agencies, wholesale and retail merchandising and light industry (33). The average annual temperature is 55° F (12.8° C) and the average annual rainfall is 41.5 in. (104.4 cm) (33). The city has separate storm and sanitary sewage collection systems. Sanitary sewage is treated at 4 waste treatment plants before discharge to area streams. Stormwater runoff is removed by a system of storm sewers and ditches. Curbs, guttering and catch basins are provided in some areas of town, while in other areas runoff is removed primarily by a system of unpaved open ditches. The stormwater system is supposed to be separate from the sanitary sewer system; however, the absence or existence of connections between the two systems is not known and few records or "as built" plans are available.

B. WATERSHEDS

Drainage for the greater portion of the city is to the southeast into a branch of the Dry Fork via Love Creek and Burgher Branch. The Dry Fork in turn discharges into the Meramec River. The outlying areas of the city to the north, west and southwest drain into the Gasconade River. Major drainage basins within the city were determined by examining the contour lines on a 7.5-min quadrangle US Geological Survey Topographic Map and were verified by field examination. The 4 basins established are shown in Figure 1.

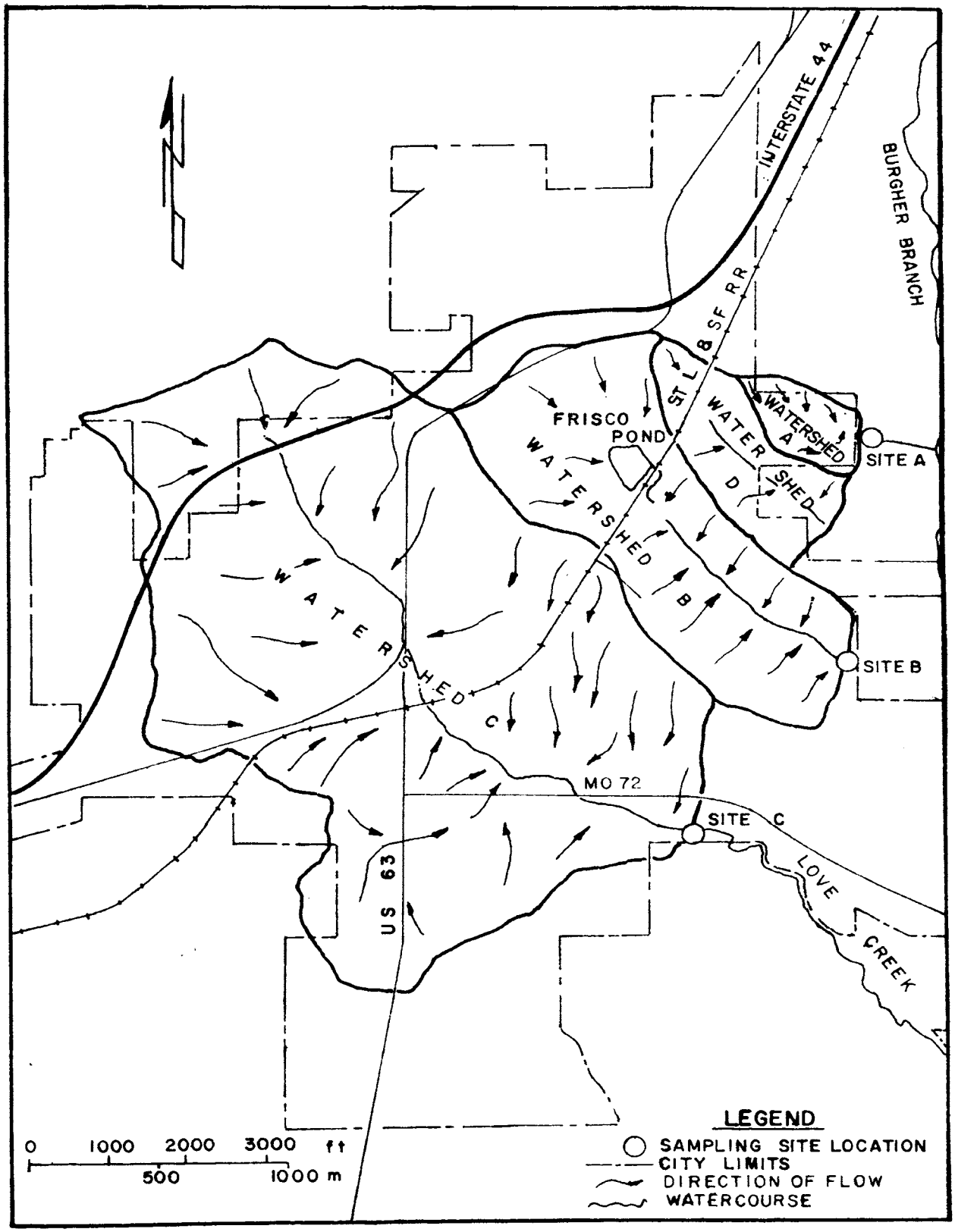


FIGURE 1. DRAINAGE BASINS AND SAMPLING SITES

Three basins were selected for study and were designated A, B and C as shown in Figure 1. The fourth basin, D, located between A and B on the map was not used because a suitable sampling location was not available at the time the study began.

1. Watershed A

This watershed drained a 31.5-acre (12.8-ha) area containing what is known locally as the "Shoe Factory Addition." This area was characterized by open ditch drainage for the most part. Residences were generally more run-down and in poorer condition than they were in the other parts of the city. An old well house, used by the city as a storage yard for pipe and electrical supplies, was located on the watershed, as was a new elementary school.

2. Watershed B

The area of this basin was 258 acres (105 ha). Located on this watershed was about one-half of the UMR campus, light commercial and motel areas, a portion of the central business district, residential areas (both single family dwellings and apartment houses), a park with a small lake, a high school with an athletic field and a swimming pool. The basin was bisected by the St. Louis-San Francisco (Frisco) Railroad tracks which run through the area on a fill. The area was drained primarily by a curb and gutter and open ditch combination. Drainage from the northern part of the basin discharged first into Frisco Pond in Schuman Park; a drainage ditch carried the pond overflow through the railroad embankment under a stone arch, and thereafter received the contribution from the remainder of the basin.

3. Watershed C

This was the largest of the watersheds sampled and had an area of 965 acres (391 ha). It included the UMR fraternity area north of Interstate 44, residential areas (both single family dwellings and apartment buildings), the UMR golf course, the Phelps County Hospital, commercial areas (including the major portion of the central business district as well as shopping centers and highway business districts), a portion of the UMR campus and the UMR power plant and coal pile. Some light industry was also located on the watershed. The major drainage feature was a channel which ran most of the length of the basin and received the discharge of open ditches, curbs and gutters and storm sewers.

C. SAMPLING SITES

The criteria used to determine the suitability of a location for the installation of a semipermanent sampling and flow recording station were:

a. Sampling of drainage from a predominately urban area.
b. Availability of 115 VAC electric power to operate the sampling equipment.
c. Suitable space to install the sampler and recorder; city property was given preference to simplify obtaining permission to install the equipment.
d. Suitable location for gaging flow.
e. Ease of access, particularly during inclement weather.
f. Security.

Three sampling locations, which in the investigator's judgement represented the best compromise of these criteria, were selected. All sites were located on city property and permission was obtained from

the Rolla City Council to install the sampling and flow recording stations. The 3 locations chosen, designated as A, B and C to correspond with the watershed on which they were located, are shown in Figure 1.

1. Site A

Site A was located in Ber Juan Park, just east of the intersection of Arkansas Avenue and City Limits Drive and adjacent to a small ditch flowing through the park. The ditch was tributary to Burgher Branch. Flow in the ditch came from 3 corrugated steel culverts, 2 [30-in. (76.3-cm) and 24-in. (61.0-cm) diam] under City Limits Drive and 1 [10-in. (25.4-cm) diam] under the driveway entering the parking lot of the park. The ditch had no dry weather flow, with the exception of runoff from occasional car washing or watermain flushing on the basin.

2. Site B

Site B was located at the foot of Irene Lane, a residential street terminating at a small creek draining Basin B. Approximately 30 percent of the basin lay above the railroad tracks, and consequently drainage from that portion flowed through Frisco Pond.

This site was selected for a number of reasons, even though the runoff sampled was a combination of pond effluent and stormwater runoff. One of the objectives of the study was to sample runoff from as much of the urban area as possible, and it was desirable to investigate different types of runoff conditions and areas. It would obviously have been better to sample the influent to the pond which entered at several points, as well as the effluent, but this would have required a large number of sampling stations and was beyond the capability of the project. The location selected at the foot of Irene Lane was as far downstream

from the pond as was practicable, while still maintaining an urban runoff character. Flow was observed at all times during the study period, although on several occasions it was quite low.

3. Site C

Site C was located in Green Acres Park near the downstream side of the bridge into the park. It sampled a stream draining Basin C which had flow at all times during the study. The bridge upstream from the sampling station provided a well defined rectangular cross-section in the stream at that point and was an excellent location for flow measurement, while the top of a concrete sewer crossing the stream bed downstream from the station formed a good control for the streamflow recorder.

IV. DESIGN AND CONSTRUCTION OF THE SAMPLING AND FLOW RECORDING SYSTEM

Although it would be possible to study stormwater runoff using manual sampling techniques, as has been done in numerous other studies, the number and frequency of samples collected and, therefore, the amount of information obtained, could be greatly increased using automatic sampling equipment. In addition, automatic equipment would permit sampling at several locations simultaneously and make it possible to initiate the sampling at each site when the runoff began. Information on the quantity and pattern of stormwater discharge is necessary to permit meaningful interpretation of the analytical data, and consequently the sampling and flow recording equipment must be properly integrated.

Many types of samplers have been developed, usually in response to a specific sampling need. Samplers may be grouped into 2 general categories, those which take instantaneous or "grab" samples and those which take samples over a period of time. The latter group, which for purposes of this discussion will be called sequential samplers, may be further subdivided into those that composite a single sample and those that take a series of samples. The composite may be flow- or time-proportional, while the series may be continuous (samples taken one right after the other) or periodic (grab samples taken at intervals).

Flow in open channels may be measured using different techniques. Various types of weirs or flumes, which relate the depth of water upstream from the weir or flume to the discharge through the device, are frequently used; this relationship must be determined experimentally, unless the weir or flume is of a standard configuration with known

discharge characteristics. Alternately, a velocity-area station may be used for which the relationship of water stage to discharge is determined empirically. Other methods of measuring flow include the use of pitot tubes, tracers and acoustic flowmeters.

A sampler was needed for this project which was relatively inexpensive, reliable, suitable for automatic operation, and which could be constructed of readily available materials. A continuous sequential sampler, capable of taking a series of samples one right after the other, was desired in order to provide flexibility in evaluating the data. By varying the length of time over which each individual sample was collected, it would be possible to examine the first flush-off using a series of comparatively short sampling intervals and, without generating an unreasonable number of samples, thereafter monitor the runoff for an extended period using longer samples. In addition, the results of laboratory analysis could be mathematically combined into either flow-proportional (using flow data from a continuous water level recorder), or time-proportional composites. Commercial sampling equipment was eliminated from consideration from the beginning because of its high cost, while a wide variety of samplers described in the literature were evaluated to determine their suitability for the project.

A. AUTOMATIC SAMPLERS

1. Samplers Used in Previous Stormwater Runoff Studies

Weibel, et al. (7) developed an automatic sampler which was equipped with a small battery-operated centrifugal pump continuously discharging to a spring-driven rotary distributor arm revolving over 36 vertical tubes arranged in a circle. Each tube was connected with a 4-l polyethylene bottle. Ten min were required for the distributor

arm to pass from one tube to the next with a total sampling time of 6 hr per revolution. The discharge flowed continuously. Plastic bottles with aluminum foil caps and special glass tubing inlets were used to collect samples for bacteriological analysis. The pump was started automatically by a float device.

Burm, et al. (23) (25) and Benzie and Courchaine (24) used a different sampler which was initially developed by Calhoun (34). This sampler operated on 110 VAC and consisted of a circular table holding 24 sample bottles equally spaced around the circumference. The table was mounted on rollers and was turned in a clockwise direction by a motor. The motor was started by a timer and stopped by a microswitch when the switch arm dropped into one of a series of holes drilled in the table. The sample was continuously pumped to the sampler and normally diverted to waste. When a sample was to be taken, a solenoid pulled the discharge tubing laterally from its waste position to a position discharging to a sample bottle. The solenoid was energized for about 1.5 sec, and as soon as the sample had been taken, the motor rotated the table bringing the next bottle into position. This sampler took a series of grab samples over a period of time.

Cleveland, et al. (8) used yet another type of sampler which they called an "inclined sequential sampler." It consisted of a frame holding 12 sample collection bottles, 6 each for bacteriological and chemical analyses. A peristaltic pump discharged to 0.25-in. (0.64-cm) ID polyethylene tubing which was fastened to an inclined board mounted above the collection bottles. The inclined tubing was equipped with a series of "T" fittings and vertical 0.25-in. (0.64-cm) ID polyethylene sections which formed an air-tight connection with each sample bottle.

Each bottle was vented with an 0.125-in. (0.32-cm) ID polyethylene air tube which ran vertically up to the top of the sampler. The intake was mounted on a float arm attached to a drainage structure and the pump was located in the sampler shelter. The sample entered the inlet, or low side, of the inclined tubing and flowed down into the first collection bottle, which was a 60-ml bacteriological sample bottle. When this bottle and its vertical riser tube were full, the water traveled up the inclined tubing to the next "T" which was connected to a 2000-ml chemical sample bottle. This sequence continued until all bottles had been filled, at which time the sample flow was composited in an air-vented 5-gal (18.9-l) overflow bottle. The sampler was turned on automatically by a microswitch fastened to the float arm carrying the intake tube, and the system was operated on 110 VAC.

None of these designs was considered adequate for the needs of the study. The rotary distributor sampler was not capable of taking samples over varying time periods, which was desirable to permit sampling the first flush-off adequately without generating too many samples later in the sampling period. The rotary table sampler was capable of taking only grab samples spaced over a period of time, while the inclined sequential sampler did not provide positive control over the sample collection time to permit accurate correlation with streamflow data. Cleveland and associates experienced some difficulties with their sampler and stated that "The capacity and rate of fill of the sequential sampling container was such that quality measurements for distinct periods of runoff could not be made once the sampled runoff began filling the overflow units" (8). Samplers used in other fields of

investigation were, therefore, considered and the automatic shift sampler was found to satisfy most of the needs of the study.

2. Automatic Shift Sampler

This sampler was developed by Hodges (35) for use in industrial wastes sampling and was designed to take continuous samples during sequential 8-hr working shifts. The device was built on a wooden frame and was provided with a variable speed, line-operated pump. The discharge tube from the pump was attached to a plastic spring-type clothespin which was placed with its jaws clamped on a long 0.25-in. (0.64-cm) threaded shaft with 1 end resting against a parallel supporting shaft. The threaded shaft was turned at a slow speed by a small electric timing motor through a chain drive, and as it turned the clothespin moved along the shaft. One-half of a 1-in. (2.54-cm) plastic water pipe was used as a trough and was placed under the threaded shaft to catch the flow from the pump discharge line. The trough was divided into sections by plastic dividers and each section was connected to a collection bottle. The speed of the shaft was such that 8 hr were required to move the discharge tubing across 1 section, and this corresponded to an 8-hr working shift at the plant being monitored. The sampler was capable of collecting 10, 8-hr shift samples without attention.

B. AUTOMATIC SEQUENTIAL STORMWATER RUNOFF SAMPLER

The sampler developed for this project was patterned after Hodge's design (35), but with several significant modifications. Provisions were made for collecting a greater number of samples, with the samples representing varying lengths of time. A means of diverting a portion of the sample to waste was devised to permit higher velocities in the

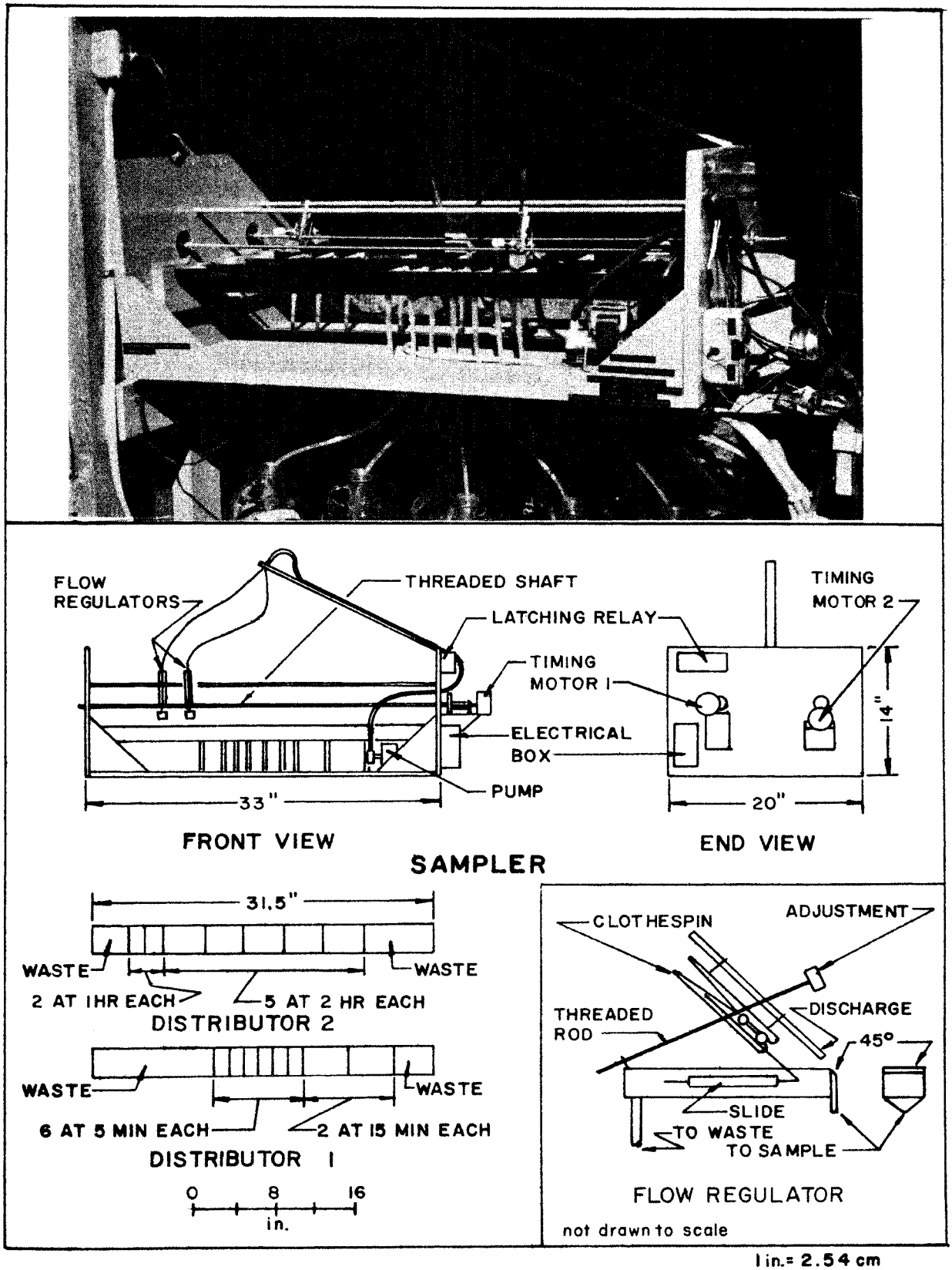


FIGURE 2. STORMWATER RUNOFF SEQUENTIAL SAMPLER

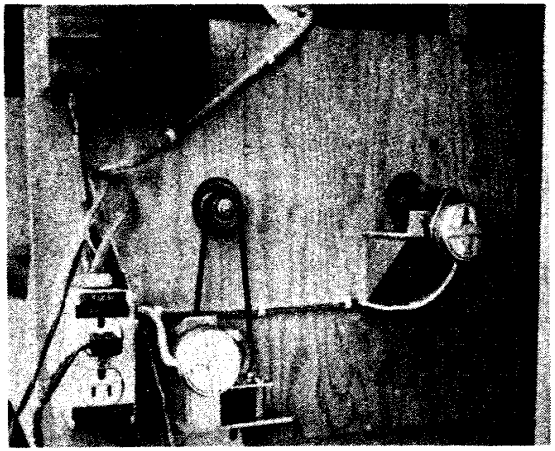
sampler lines and prevent deposition of solids, and automatic starting of the pump and sampler was provided. The modified sampler, shown in Figure 2, consisted of a wooden frame on which were mounted 2 horizontal troughs divided into sections of varying lengths. A small pump drew water from the stream and pumped it to flow regulators, mounted on a horizontal threaded shaft above each trough, which divided the flow into a portion that drained to waste and a portion that discharged to the trough. A small electric motor turned the shafts and moved the regulators longitudinally over the troughs. The sample drained from each trough section into a collection bottle, and the length of time over which the sample was collected was determined by the length of the sections and the speed of the shaft.

1. Sampler Frame

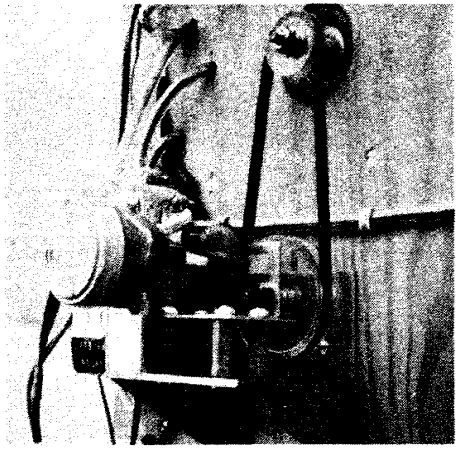
The frame (Figure 2) was constructed of 0.75-in. (1.9-cm) exterior grade plywood fastened together with glue and screws, and consisted of a base and 2 end pieces. Two plywood blocks with semi-circular cut-outs were fastened on each end piece to support the distributor troughs. A 0.25-in. x 1-in. (0.64-cm x 2.54-cm) support arm about 15 in. (38 cm) long was fastened to the upper portion of one end piece with an angle bracket and was used to support the tubing leading from the pump to a "Y" dividing the flow to the 2 regulators.

2. Distributor Troughs

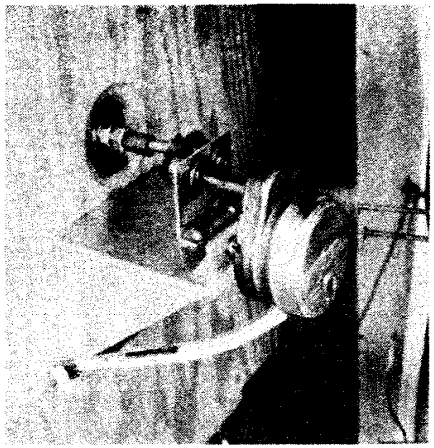
Each trough (Figures 2 & 3d) was made of a piece of 3-in. (7.62-cm) ID Black ABS plastic pipe which had been cut in half longitudinally and fitted with 0.25-in. (0.64-cm) thick plastic dividers provided with a 45^{o} bevel on the upper edge. The dividers were positioned in the front trough to produce 6, 5-min (sampling time) followed by 2, 15-min sections,



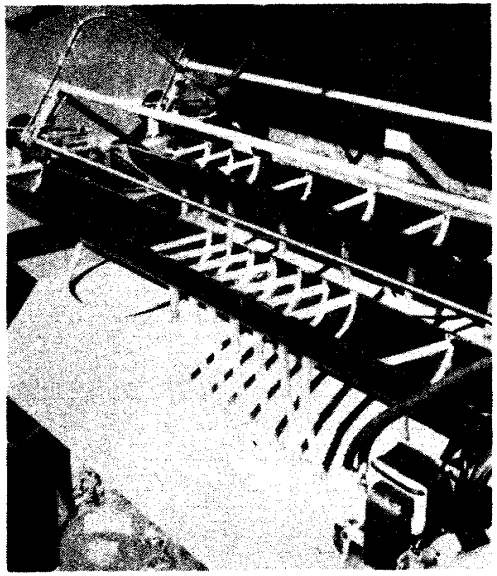
a. Electrical Components and Gearing



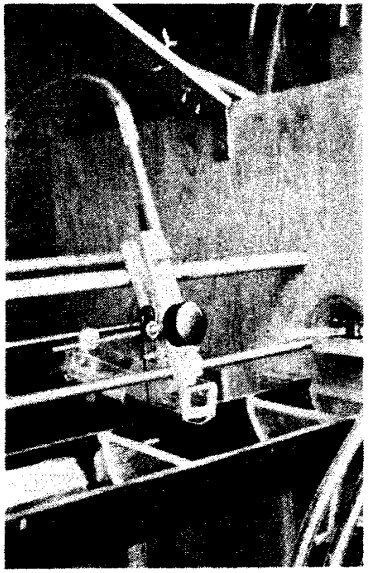
b. Gearing - Distributor 1



c. Gearing - Distributor 2

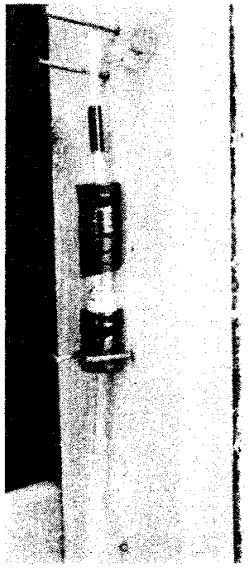


d. Distributor Troughs



e. Flow Regulator

f. Pump



g. Check Valve

FIGURE 3. STORMWATER RUNOFF SEQUENTIAL SAMPLER COMPONENTS

while the back trough was provided with 2, 1-hr sections followed by 5, 2-hr sections. Since the gearing arrangement for the front distributor (Figure 3b) included plastic pulleys which were turned to approximate dimension only, it was necessary to measure the actual rate of travel for the front shaft of each of the 3 samplers and space the dividers accordingly. The spacing of the dividers in the back trough was the same for each sampler because the back shaft was driven (Figure 3c) through a completely geared arrangement. The dividers were cut to provide a snug fit and were anchored in place with epoxy cement. A length of 0.25-in. (0.64-cm) ID Tygon tubing was installed into a hole drilled in the bottom of each section of the distributor trough using a press-fit and was used to carry the sample from the trough to the sample bottle.

3. Timing System

The threaded shaft was a commercially available threaded 0.25-in. (0.64-cm) steel rod 36 in. (91.5 cm) long, with 20 threads/in. (7.9 threads/cm). It was supported on bearings made by glueing with epoxy cement child's roller skate wheels in holes cut in the end pieces of the frame. Standard nuts and lock washers were used to hold the shaft in place, and to minimize binding and adjustment problems it was found expedient to secure the shaft to only one of the bearings.

The shafts were turned by 1 rpm synchronous timing motors* developing 0.104 lb-ft (1440 cm-g) torque. The speed of the front shaft was increased to approximately 6 rpm using a gear and belt drive (Figure 3b), and at this speed the flow regulator traveled down the shaft at a speed of approximately 0.3 in./min (0.76 cm/min).

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*Hansen K12RC, obtained from the Allied Electronics Corporation, Chicago, IL.

The back shaft was turned through a gear drive (Figure 3c) which reduced the speed to 0.66 rpm moving the flow regulator down the shaft at a rate of 1.98 in./hr (5.03 cm/hr).

A microswitch was installed at the end of the front shaft, and when actuated by the moving flow regulator, stopped the front timing motor and started the rear timing motor. An additional microswitch was incorporated into each of the final 2 samplers built. It was mounted at the end of the back threaded shaft in such a position that the clothespin would strike the actuating arm on completion of travel, thereby shutting off the timing motor.

4. Flow Regulator

Initially, the flow to each distributor trough was regulated by squeezing the tubing with a screw clamp. This method proved unsatisfactory because solids in the sample tended to accumulate in the constricted area, either reducing or stopping the flow. The problem was solved with the development of a flow regulator (Figures 2 & 3c) which consisted of a plastic trough with a bevel ground on one end piece. The trough was mounted under the clothespin on slides in such a manner that the beveled edge could be moved in and out of the sample stream by a screw arrangement. Full flow was maintained in the lines up to the point of discharge, and the beveled edge functioned as a flow divider; the portion of the sample stream in front of the edge was diverted to the distributor trough and thence to the sample container, while that in back of the edge was wasted through a drain line.

5. Pump

The sample was pumped from the stream using a small, inexpensive gear-type pump* (Figure 3f) which was reported by the manufacturer to have a maximum capacity of 42 oz/min (1.24 l/min) and a maximum head of 15 psi (1.06 kg/sq cm) gage. Rating curves (Figure 4) were developed by connecting a pump to a mercury manometer and operating it at either 0 discharge head or 0 suction head at different flow rates. The maximum suction head was found to be about 30.5 ft (9.30 m) of water and the maximum pressure head 21.5 ft (6.55 m). The minimum flow required was estimated to be 0.075 gpm (0.21 l/min) and could be delivered by the pump at either 14.8 ft (4.51 m) pressure head or 29.2 ft (8.90 m) suction head. Maximum static and dynamic head loss in the sampling system was estimated at about 17 ft (5.18 m) of water. This being the case, it was decided that the best location for the pump was on the sampler itself; this made possible maximum use of the suction head and afforded protection for the pump by mounting within the sampler shelter.

Although this type pump was expected to be self-priming, this was not actually the case and it was necessary to provide a check valve to keep the pump and sample lines full of water at all times to permit automatic operation. The valve (Figure 3g) was devised from a piece of glass tubing 0.75-in. (1.9-cm) diam and 2.2-in. (5.6-cm) long which was fitted with rubber stoppers pierced with a short length of glass tubing. A 0.5-in. (1.27-cm) twist drill was used to make a concave

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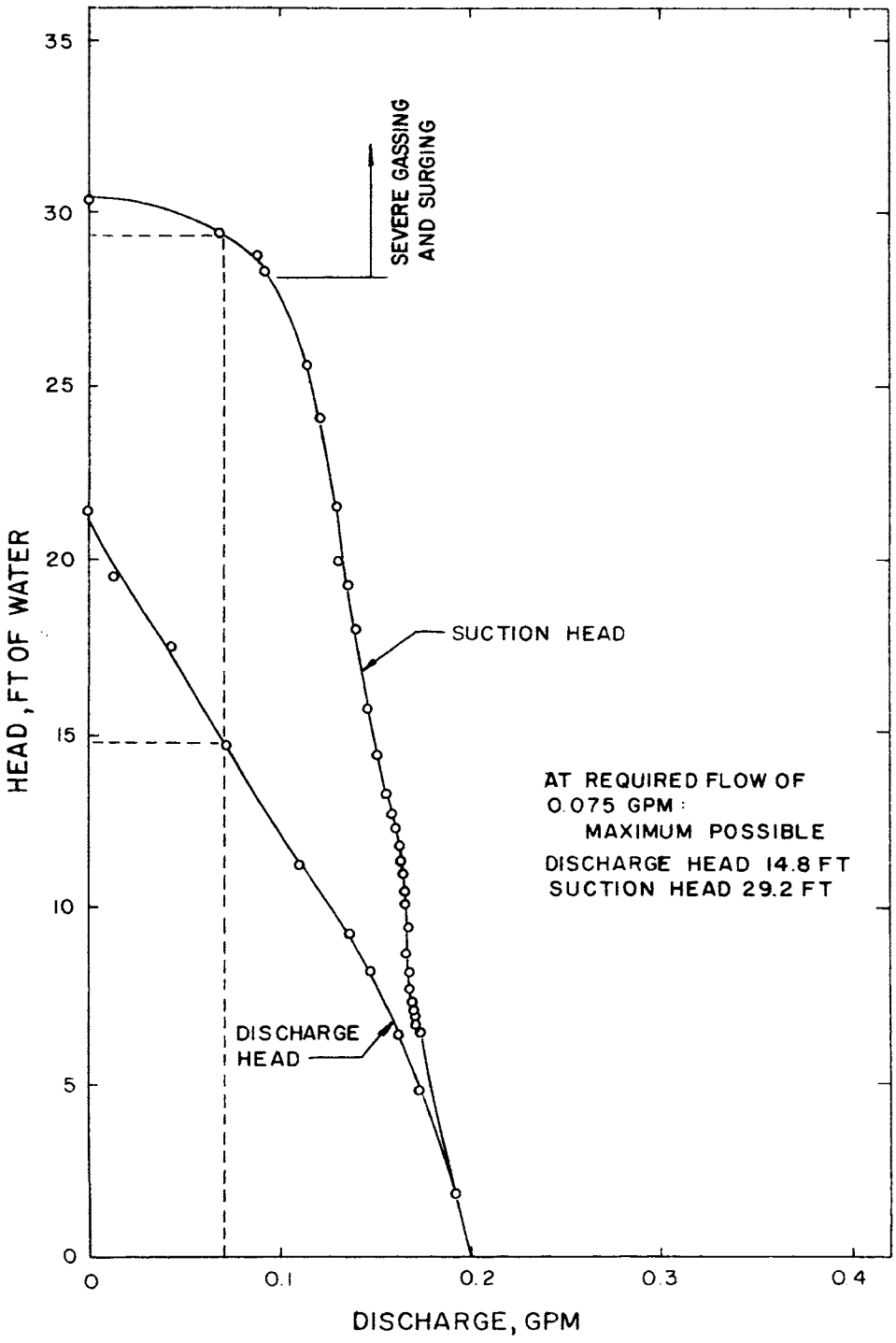
*Model 7012, a product of the Cole-Parmer Instrument Company, Chicago, IL.



NOTE: TO CONVERT GPM TO L/MIN MULTIPLY BY 3.785; TO CONVERT FT TO M MULTIPLY BY 0.3048.

FIGURE 4. PUMP RATING CURVE

seat for an ordinary glass marble which was used as the valve. The completed check valve was placed in a vertical position on the suction side of the pump. A special device was developed for priming the sampler lines. It consisted of a small hand-operated air pump which was used to force water from a 1-gal (3.785-l) bottle into the sampler lines through a priming tap on the suction side of the pump.

6. Sample Bottles

These were either 2.4-l acid bottles or 1-gal (3.785-l) soft drink syrup bottles.

7. Tubing Arrangement

A schematic diagram of the flow pattern in the sampler is shown in Figure 5b, together with the sizes of tubing used.

8. Electrical Wiring Diagram

Wiring diagrams for the prototype and modified samplers are shown in Figure 6. Also shown in this figure is the wiring diagram for the latching relay which was provided for each sampler. The function of this relay (Figure 3a, upper left corner) was to lock the sampler in the "on" position once it had been activated by the float switch, thereby enabling sampling of the receding flow as well.

C. WATER LEVEL RECORDER

Streamflow data were obtained at each sampling station using a water level recorder.* The recorder was placed on the top of a stilling well connected to the stream and was housed in a steel shelter to protect it from vandalism. It was equipped with a pen which was actuated by a counter-balanced float resting on the surface of the

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*Stevens type A35, a product of Leupold & Stevens Instruments, Inc., Portland, OR.

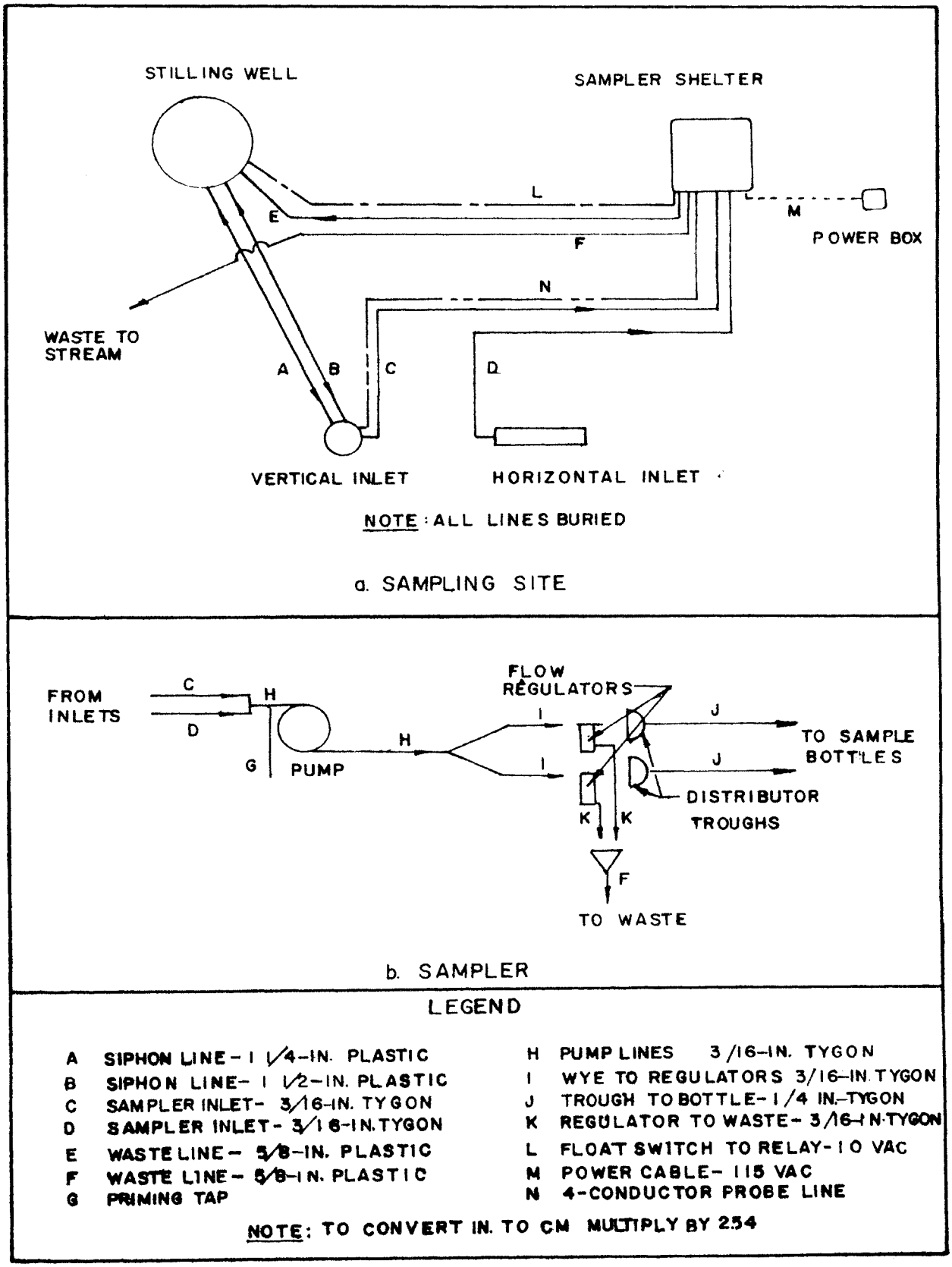


FIGURE 5. FLOW SCHEMATIC DIAGRAM

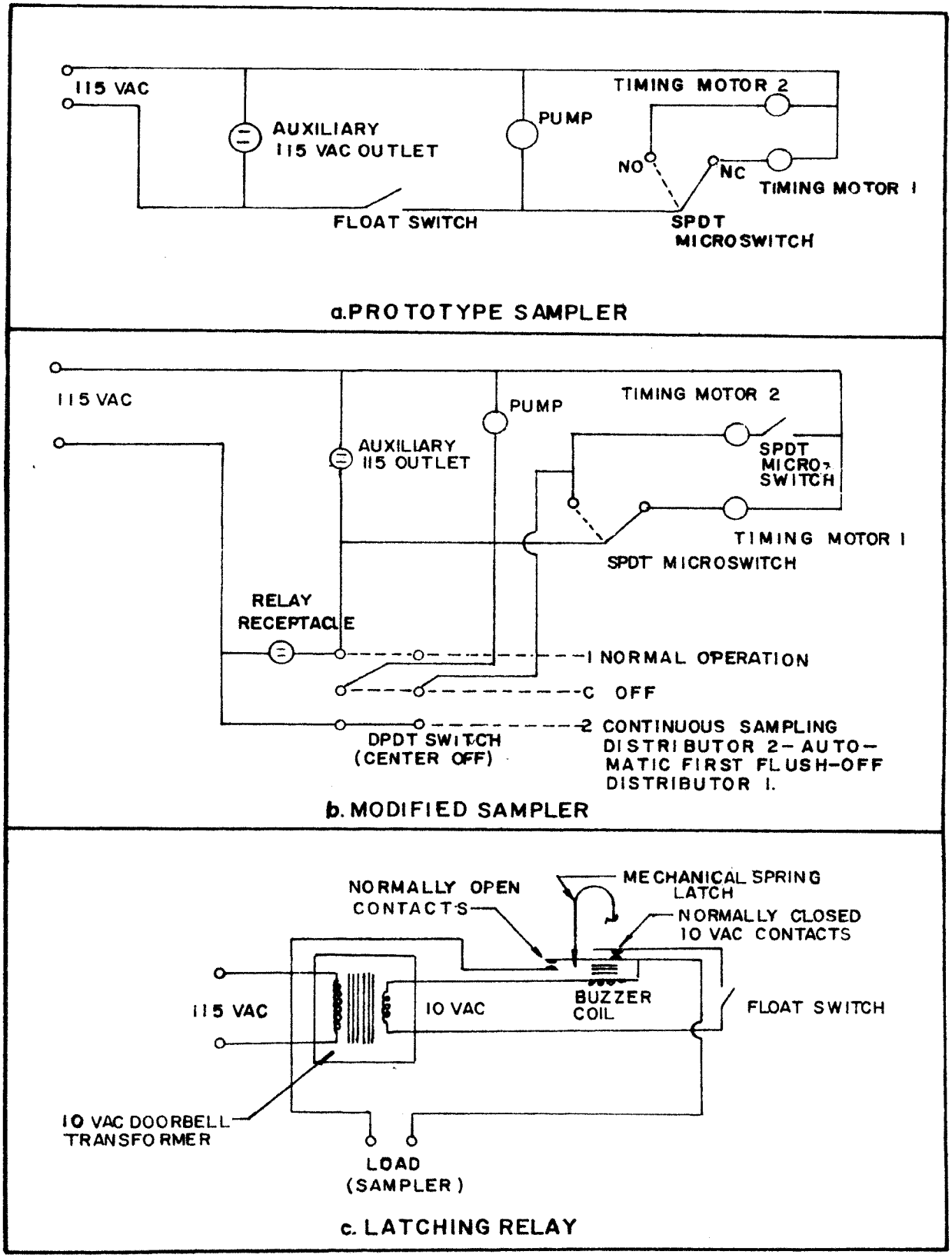


FIGURE 6. ELECTRICAL SCHEMATIC DIAGRAM

water in the well. The pen traced a continous record of the water level on chart paper which was pulled through the recorder by a spring-driven clock at the rate of 2.4 in./day (6.4 cm/day). It was necessary to develop a rating curve for each location in order to translate recorded data into streamflow.

D. SAMPLING AND FLOW RECORDING SYSTEM

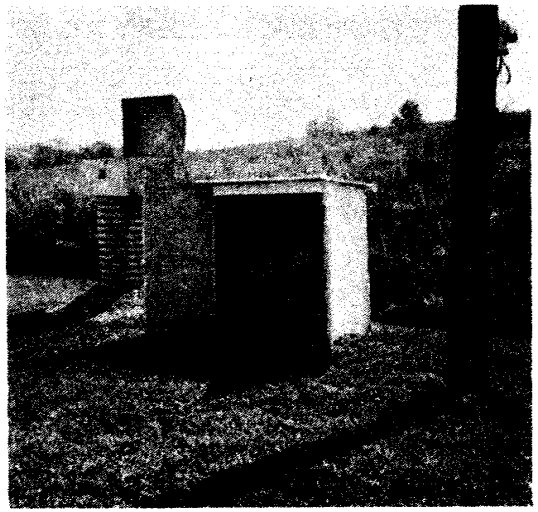
Each field installation was provided (Figure 7a) with a flow-activated automatic sampler located in a suitable shelter, a continuous streamflow recorder enclosed in a steel shelter mounted on a stilling well, an inlet system, a metered power source, a staff gage and a streamflow control and metering station. A photograph of each sampling station is shown in Figure 7.

1. Power Source

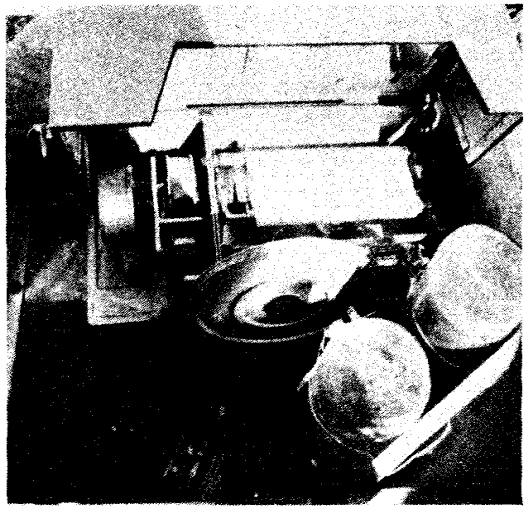
A fused, weatherproof switch box was mounted together with a watt meter on a utility pole near each sampling station. Power was transferred to the shelter via an underground cable which terminated inside the shelter in a standard receptacle box. A lock was provided for each switch box cover.

2. Sampler Shelter

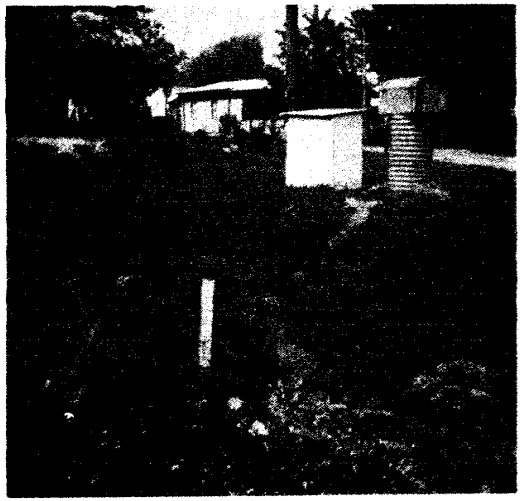
Shelters were built of 2-in. x 4-in. (5.1-cm x 10.2-cm) framing covered with asphalt-impregnated building sheathing. The roofs were constructed of 1-in. (2.5-cm) pine boards covered with muslin laid in wet latex paint. The shelters were provided with 2-ft (0.61-m) long extensions of the corner posts which were anchored into holes drilled into the ground with a post-hole auger and then backfilled and tamped.



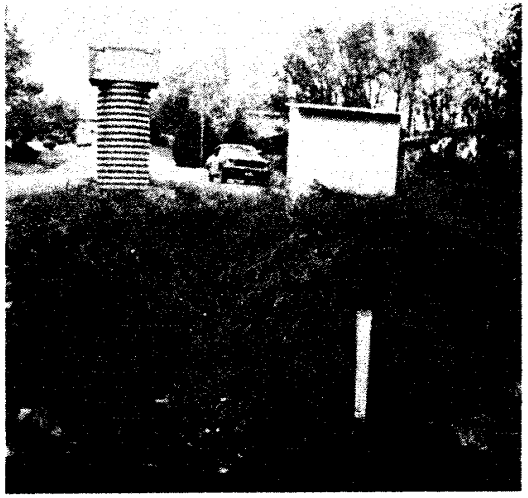
a. Typical Field Installation



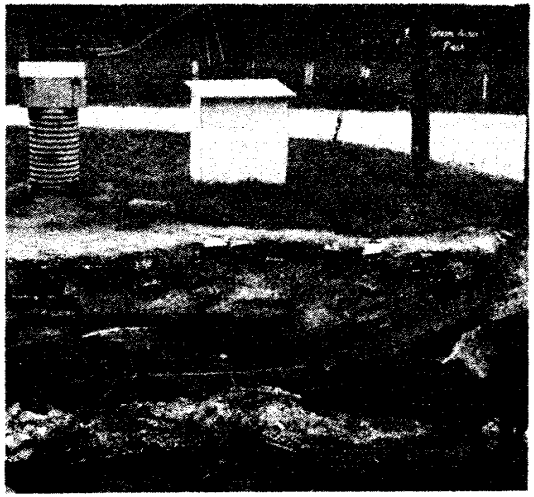
b. Flow Recorder



c. Site A - Ber Juan Park



d. Site B - Irene Lane



e. Site C - Green Acres Park

FIGURE 7. SAMPLING AND FLOW RECORDING SYSTEM FIELD INSTALLATIONS

3. Stilling Well

Holes for the stilling wells were bored to about a 3-ft (0.91-m) depth with a tractor-mounted auger furnished by the UMR Buildings and Grounds Department. The wells were finished by hand to a depth approximately 1 ft (0.30 m) below the low water level at each site, averaging about 7 ft (2.13 m). Each well was cased with 2-ft (0.61-m) diam corrugated pipe cut to a length sufficient to project above the ground 2 to 3 ft (0.61 to 0.91 m). The steel shelters for the flow recorders were bolted to the top of the stilling wells.

4. Inlet System

In the early part of the study, inlets for the sampler and stilling well were simply screens over the end of the tubing. The tubing was anchored in place using large rocks and wooden stakes driven into the streambed. To overcome sediment accumulation problems in the siphon lines, the corresponding inlets were later on placed inside a large coffee can, with holes drilled in the lid, which served as a sediment chamber; the can was imbedded in the stream and weighted with rocks. All these devices proved unsatisfactory in that it was difficult to keep them from washing out during large flows.

In the latter part of the study, a more permanent inlet system was devised. Two separate intakes were provided for each sampler (Figure 5a). The first (Figure 8c) intake was constructed of 0.5-in. (1.27-cm) diam galvanized pipe and fittings, window screen wiring and 0.25-in. (0.64-cm) mesh hardware cloth. The second inlet was a plain piece of tubing located in the intake structure for the stilling well. This structure (Figure 8b) consisted of a 2.5-ft (0.76-m) piece of 3-in. (7.6-cm) ID plastic pipe set vertically in the stream bed. The

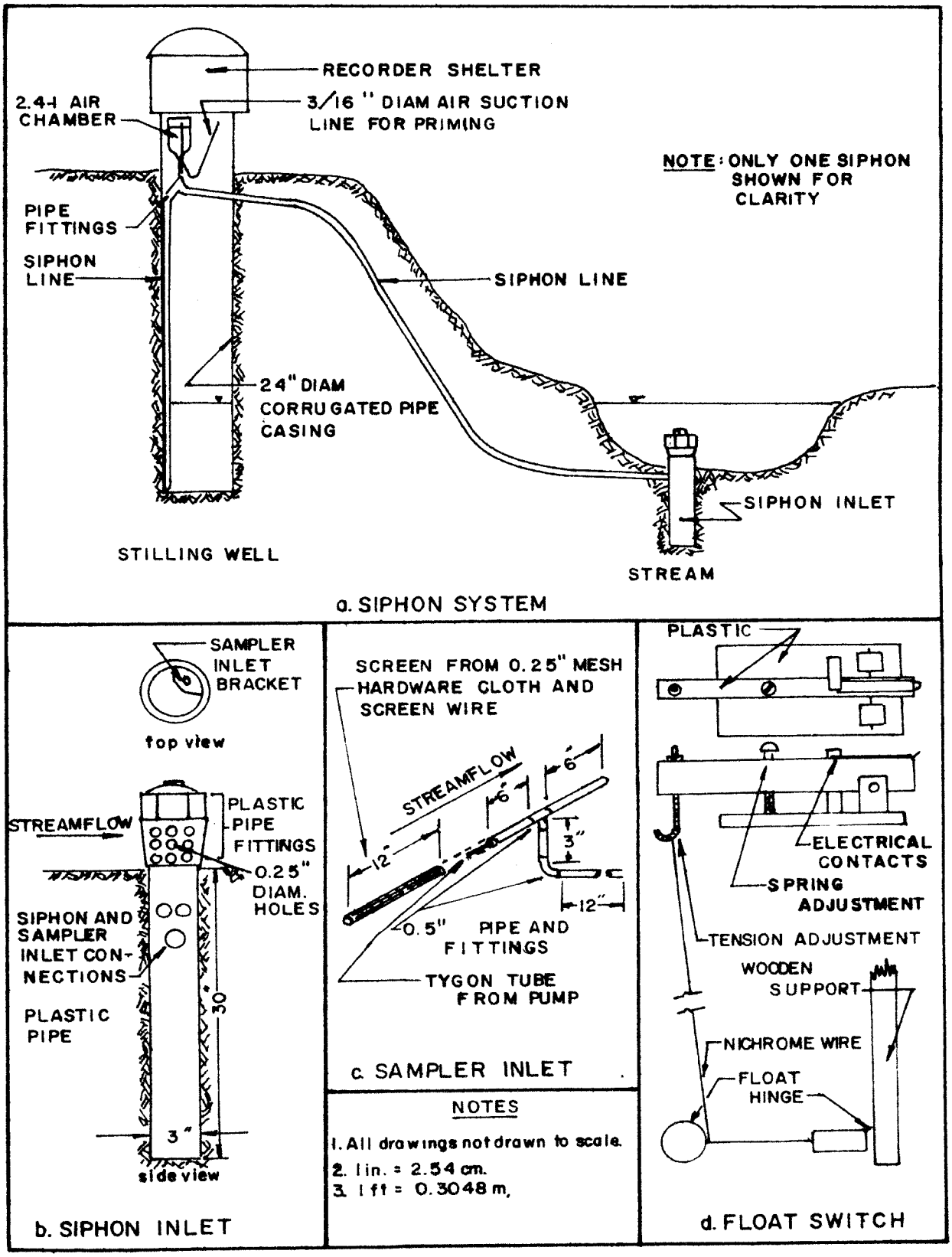


FIGURE 8. SIPHON SYSTEM, INLETS AND FLOAT SWITCH

pipe served as a sediment chamber and aided in keeping the siphon lines from clogging. It was capped with a plastic clean-out fitting which was attached with a standard plastic adaptor and provided access to the inside of the pipe for cleaning and service. Numerous 0.25-in. (0.64-cm) diam holes were drilled in each clean-out fitting to facilitate free flow of water into and out of the pipe. To securely anchor the intake structures, an area of the stream bed was cleared and excavated to a depth of 6 to 9 in. (15.7 to 22.8 cm) for the sampler inlet and 2 ft (0.61 m) for the siphon inlet. The inlet devices were placed and concrete was poured around them.

5. Float Switch

The sampler was turned on automatically by a rise in water level in the stream. This was accomplished by a float switch, which was initially housed inside a 5-gal (18.9-l) solvent can placed at the edge of the stream. The system consisted of a mercury switch mounted on a pivoted arm fastened to a float. This arrangement was found to be unsatisfactory because the housing was not sturdy enough to resist the attacks of vandals, and it was difficult to properly anchor in the stream; in addition, sediment frequently clogged the small lines used as inlets to the container.

To overcome some of these difficulities, the float switch was redesigned and placed inside the heavy corrugated pipe used for a stilling well. The modified system (Figure 8d) consisted of an ordinary toilet tank float attached to a 10-in. (25.4-cm) arm hinged to a 1-in. x 2-in. (2.54-cm x 5.08-cm) wooden support fastened to the stilling well. The hinge was placed at about the normal low water level and the float was free to rise and fall with the changes in

water level, without, however, interfering with the flow recorder float. A nichrome wire connected the float and the switch and the weight of the float held the switch in the open position.

A 3-conductor electrical line (Figure 5a) was placed underground between the sampler shelter and the recorder shelter and 2 of the wires were used to connect the float switch to the latching relay on the sampler. (The extra conductor was a spare for future use.) As the water level in the well rose with the level in the stream, weight was removed from the float switch arm; a spring pushed the arm upward, closing the contacts and activating the latching relay. The improved float switch worked very well and was easily adjustable. The author observed its functioning several times under actual start of runoff conditions.

6. Shore to Stream Connections

All connections between the two shelters and the shelters and the intake structures in the stream were buried to a depth of 6 to 9 in. (15.7 to 22.8 cm) in order to improve the appearance of the site, deter vandalism and help prevent freezing of the lines during cold weather. A schematic diagram of all connections is shown in Figure 5a.

Sampler intake lines were placed inside garden hose or plastic pipe for physical protection and terminated at a "T" just below the check valve. A screw clamp was used to clamp off the unused line, which was kept primed and was readily available as a back-up in case the main line was washed out or damaged. A waste line, constructed from garden hose, was provided to carry excess sample flow back to the stream. It was fitted with a funnel at its upper end and ran to a discharge point downstream from the intakes. A second waste line

was also provided from the shelter to the stilling well in order to enable use of the sampler pump to flush the well or, by discharging through a water heater, heat the siphons in freezing weather. In addition, a 4-conductor electrical cable was provided between the sampler shelter and the siphon intake for future installation of a dissolved oxygen and temperature probe, or other type of probe.

The stilling well was connected to the stream by means of 2 siphons (Figure 8a) using a method described by Yost and Naney (36). While 1 siphon would have been sufficient, 2 were provided as a safety measure; the first siphon was constructed of 1-in. (2.54-cm) plastic pipe and the other was made of 1.25-in. (3.17-cm) pipe (Figure 5a). The siphons were sloped upward to a high point located inside the stilling well and then dropped vertically downward, terminating beneath the water level in the well. An air chamber, made of a 2.4-l acid bottle, was provided for each siphon and was mounted inside the recorder shelter on top of the well where it could be reached easily for service. The air chamber was connected to the high point of each siphon with a length of garden hose using standard galvanized and plastic pipe fittings. The siphon and air chamber were primed with water by attaching a vacuum pump to a special fitting on each air chamber. Numerous small leaks were detected and were repaired using a silicone rubber compound.

7. Control, Metering Section and Staff Gage

The velocity-area method used for measuring streamflow required that a control, a metering section and a gage be provided at each sampling site. The control was a cross-section or portion of the channel that determined the relationship between stage and discharge

at that point and for a distance upstream. Adequate controls were not available at Sites A and B and it was, therefore, necessary to provide artificial controls. At Site A discarded concrete test cylinders were placed in the stream bed, while at Site B a low dam was built from rock and broken concrete pavement. An artificial control was already available at Site C in the form of the top of a concrete trunk sewer crossing under the stream bed.

The metering section was a cross-section of the stream where the discharge was measured. The metering section at Site A was established at a point midway between the control and the intake for the siphon and at Site B it was taken to be a section of the stream adjacent to the stilling well. At Site C, the concrete box culvert carrying the flow under the bridge into the park was used as the metering section, and to facilitate measurement stations were marked on the edge of the bridge deck at 1-ft (0.30-m) intervals.

A standard staff gage, fastened to a 2-in. x 6-in. (5.1-cm x 15.2-cm) board was provided at each sampling station to serve as a reference for the streamflow recorder. At Sites A and B, the boards were anchored in concrete at both the back and base, while at Site C the board was attached to the concrete headwall of the bridge using epoxy cement and special nails.

E. MATERIAL COST AND TIME ESTIMATE

The approximate cost of materials and time required for the flow recording station, were as follows:

Component	Cost $	Construction & Installation Time hr
Sampler, including pump	60.00	20.5
Sampler shelter	19.00	12.0
Flow recorder and stilling well	- -	40.0
Miscellaneous (power boxes, wire, tubing and fittings)	16.00	--
Total	95.00	82.5

Costs, which do not include labor, may be expected to vary, depending on the materials and equipment available. In this project, flow recorders and pipe for the stilling wells were available without charge from a previous investigation. Construction time, and especially installation time, may also be expected to vary considerably depending on local conditions and the availability of power equipment. A great deal of manual excavation was necessary in installing the stilling wells and the time required could have been significantly reduced with the proper equipment.

F. PRECIPITATION GAGE

Rainfall data was obtained from the Environmental Science Services Administration Weather Station on the UMR campus.* This station was located on the watershed contributing runoff to Site B and was equipped with standard and a 24-hr weighing-type rain gage.** Since the recorder charts were periodically sent to the federal agency, a quantity of charts was printed and used to trace the recorder data

*This station was serviced by the UMR Geophysical Observatory.
**Universal Rain Gage, a product of the Belfast Instrument Company, Baltimore, MD.

with the aid of a light table. This was usually done monthly, just prior to the mailing of the charts. Additional weather data were obtained as needed from the records of the UMR weather station.

V. FIELD EVALUATION

A. FIELD PROCEDURES

1. Sampling

The samplers were kept ready at all times in anticipation of rainfall. During the early part of the study, it was necessary to start the samplers manually. After a satisfactory float switch had been developed, the units were turned on automatically by the rising water level in the stream; however, as soon as precipitation began, the sites were visited to make certain that the equipment was operating properly. Sampling continued until the stream flow had receded to approximately normal stage, or in the case of a number of closely-spaced storms, until no more sample bottles were available. Samples were generally removed from the samplers and transferred to a 5° C walk-in incubator* in the laboratory at least every 4 hr. When overnight sampling was necessary, the samples were picked up about midnight and transferred to the laboratory. The overnight samples were collected and refrigerated early the next morning.

Grab samples for bacteriological analysis were taken at Sites B and C during the runoff period of the storm on August 7, 1971. Sterile bacteriological sample bottles and the recommended standard sampling technique were employed. The samples were transferred to the laboratory within 4 hr and refrigerated at 5° C. Analysis of these samples began within 24 hr after collection. A grab sample and a

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*Model 704A, a product of Lab-Line Instruments, Inc., Melrose Park, IL.

sample of the pump discharge were collected at each site during one of the sampling periods. These were used to provide an indication of the ability of the automatic equipment to collect representative samples of the streamflow.

2. Flow Measurement

Velocity and depth measurements were made as often as possible at each site during the runoff period. A pygmy current meter* was used for measuring the velocity through each metering section. Where flows were too low to be measured by the current meter, an estimate was obtained by floating a leaf or other object over a course of known cross-sectional area and measuring the time required to traverse a known distance. Two measurements at each site during the runoff from a particular storm were usually all that were possible when other duties were taken into account.

Measurement of the velocity and depth of flow was generally done at 1-ft intervals across the stream. The cross-sectional area of the stream was divided into an equal number of increments and the discharge through each section was computed assuming its area to be a trapezoid and using the velocity measured at the center of the increment. The individual discharges through the incremental areas were then added to obtain the total discharge for the stream at that time. Although measurements were made at all sites, rating curves could not be developed at Sites A and B because of shifting controls. The rating

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*Manufactured by the Scientific Instrument Co., Inc., Milwaukee, WI; this meter was last calibrated by the National Bureau of Standards on August 2, 1965.

curve for Site C is presented in Figure 9. The stage of the stream was read on the staff gage each time a site was visited during the course of the runoff and the value obtained was noted on the water level recorder chart. The purpose of this was to provide a check on the response and possible clogging of the siphons.

3. Precipitation Data

Information on precipitation events which occurred during the period of this study is given in Table II which was prepared on the basis of data obtained from the UMR Weather Station. Events totalling less than 0.10 in. (0.25 cm) were excluded because they were found to produce no runoff from the basins studied. The antecedent dry period for the storms sampled was calculated and is also reported in Table II. This period was considered to be that time prior to the precipitation event during which no runoff occurred, and was determined by examining the weather station and flow recorder data and taking into account the amount of rainfall, previous precipitation, temperature conditions (for snow or ice melt-off) and field observations.

B. LABORATORY PROCEDURES

A broad group of parameters was selected for study and the procedures recommended in Standard Methods for the Examination of Water and Wastewater (37) were followed, unless otherwise noted. The parameters were divided into 3 groups, chemical, physical and bacteriological.

1. Chemical Parameters

a. Total Alkalinity

Alkalinity was determined by the potentiometric method (37, p.370 & 52). A sample was titrated with 0.02N sulfuric acid to a pH of 4.5

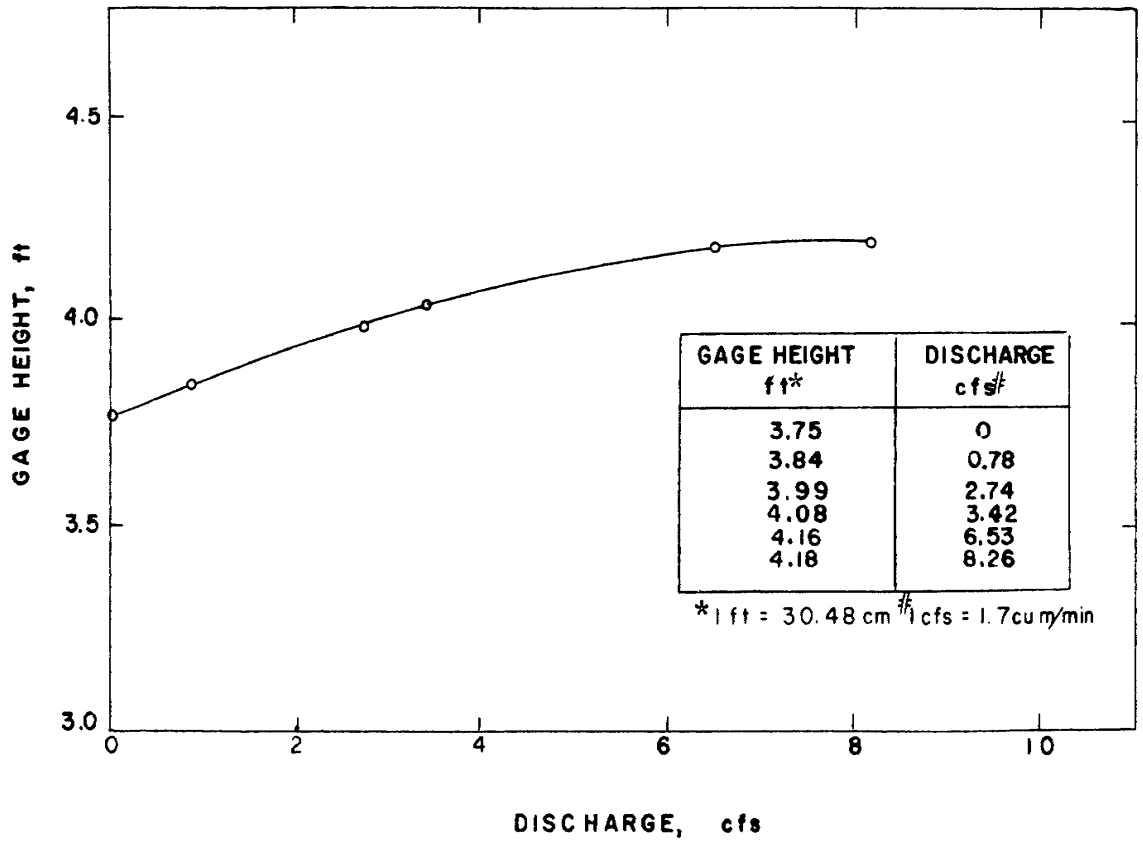

FIGURE 9. RATING CURVE FOR SITE C

TABLE II. SIGNIFICANT PRECIPITATION EVENTS

Date	Type *	Duration			Intensity		Precip-itation#	Temperature		Antecedent Dry Period
					Avg	Max		Max	Min	
		Start	End	hr	in./hr**		in.**	°F##		days
1/2	R	2100	2400	3.0			0.10	46	36	
1/3	R	0200	1430	12.5			0.35	51	19	
1/17-1/18	S	1900	1100	16.0			0.12	31	6	
2/4	R	1130	1400	2.5	0.24	0.60	0.60	48	26	31
2/21-2/22	R	1250	0030	11.6	0.009	-	0.10	40	32	17
3/6	R	0005	1200	12.0	0.10	0.40	1.20	58	33	12
3/14	R	2030	2200	1.5			0.10	74	46	
3/24-3/25	R	2200	1130	13.5			0.10	34	28	
4/4	S	0900	1700	8.0	0.04	-	0.31	38	32	9
4/5-4/16	S	1700	0900	16.0	0.02	-	0.29	43	30	1
4/13	R	0230	1200	9.5			0.10	86	49	
4/20	R	1330	1700	3.5			0.50	83	59	
4/23	R	0130	0630	5.0			0.38	67	45	
4/25	R	1630	2000	3.5			0.10	72	46	
4/27	R	0600	0730	1.5			0.48	80	55	
5/1	R	1800	2300	5.0			0.51	68	45	
5/10	R	0330	0930	6.0	0.15	-	0.88	76	58	8
5/19	R	0630	1000	4.5			0.45	80	58	
5/20	R	0400	0500	1.0			1.65	70	49	
5/20-5/21	R	1500	0900	18.0			0.55	77	52	
6/1	R	0400	0455	0.9	0.13	-	0.14	83	61	11
6/2	R	1405	1700	3.0	0.15	3.16	0.48	81	64	1
6/10	R	0830	1100	2.5	0.06	-	0.14	83	64	7
6/12	R	1700	1800	1.0			0.25	90	71	
6/13	R	1200	1300							
		1500	1600							
		2000	2100	3.0			0.37	92	68	
6/14	R	1130	1200	0.5			0.67	90	68	
6/15	R	1630	1700	0.5			0.10	81	66	
6/18	R	1000	1045	0.75			0.25	85	71	
6/19	R	1800	1845	0.75			0.10	90	72	
7/10	R	2000	2155	2.0			1.50	96	71	
7/11	R	1130	1300	1.5			0.12	83	69	
7/18	R	0930	1000	0.5			0.12	97	69	
7/23	R	1440	1630	2.0			0.33	88	70	
7/28	R	1700	2000	3.0			0.30	85	60	
8/7	R	1230	1310	0.6	0.25	0.30	0.15	74	67	9
8/11	R	1530	1600	0.5			0.15	96	69	

*R = Rain, S = Snow.
**To convert in./hr to cm/hr and in. to cm multiply by 2.54.
#Events producing <0.10-in. precipitation are not included.
##To convert °F to °C multiply by 0.555 (°F - 32).

and then to a pH of 4.2 using a pH meter* to determine the end points. The total alkalinity, as mg/l $CaCO_3$, was calculated by the relationship [(2C-D) x N x 50,000]÷(ml sample), where C and D represented the volume of acid required to reach the pH of 4.5 and 4.2 respectively, and N was the normality of the acid used.

b. Total Hardness

Hardness was measured by the EDTA titrimetric method (37, p.179) using Univer II** indicator powder and standard EDTA titrant.** The results were expressed as mg/l of equivalent calcium carbonate.

c. Ammonia Nitrogen

Ammonia nitrogen was determined by direct nesslerization (37, p.453 & 226). This method was chosen because the large number of samples being examined and the limited distillation equipment available made the preliminary distillation step impractical. One ml of zinc sulfate solution was added to 100 ml of sample and throughly mixed. The pH was adjusted to 10.5 using 6N sodium hydroxide, the precipitate was allowed to settle and the supernatant was clarified by centrifugation.# Fifty ml of the clarified sample were transferred to a nessler tube, a drop of EDTA reagent was added and mixed with the sample; 2 ml of nessler reagent were then added and the mixture was allowed to react for 15 min before the color was read on a spectrophotometer## at 425 mμ. The concentration of ammonia nitrogen was determined from a calibration curve and expressed as mg/l N.

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*Zeromatic, a product of Beckman Instruments, Inc., Fullerton, CA.
**Supplied by the Hach Chemical Company, Ames, IA.
#A Model CL centrifuge was used; it was a product of the International Equipment Co., Needham Heights, MA.
##Spectronic 20, a product of Bausch & Lomb, Inc., Rochester, NY.

d. Total Kjeldahl Nitrogen

To determine total kjeldahl nitrogen (37, p.469 & 246), an appropriate volume of sample (usually 250 ml) was measured into an 800 ml kjeldahl flask. Fifty ml of digestion reagent and a few microporous boiling chips were added, the flask was placed in the kjeldahl digestion unit* and the sample was digested until at least 30 min after clearing following the formation of sulfur trioxide fumes (total digestion was on the order of 3 hr). The sample was allowed to cool and was then diluted to 300 ml with deionized water.** Phenolpthalein and enough sodium hydroxide-sodium thiosulfate reagent (usually about 50 ml) were introduced by allowing the reagent to run down the side of the flask to form an alkaline layer at the bottom. The flask was then connected to a previously-steamed distillation unit* and mixed by swirling. The sample was steam-distilled until 200 ml of distillate had been collected in 50 ml of indicating boric acid solution. The ammonia in the distillate was determined by titration with 0.02N sulfuric acid and the concentration of total kjeldahl nitrogen was calculated and expressed as mg/l N.

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*Two 2-unit portable digestion and distilling apparatus were used; they were products of the Precision Scientific Co., Chicago, IL.

**It was necessary to use regular laboratory deionized water instead of specially-prepared ammonia-free water because facilities for preparing the large volumes of ammonia-free water required for the number of determinations being performed were not available. Distillation in the 330-ml/hr capacity glass still available could not keep up with demand, and a special ion-exchange resin which had been ordered did not arrive in time to be of use in this project.

e. Organic Nitrogen

The concentration of organic nitrogen was calculated by subtracting the value determined for ammonia nitrogen from the value obtained for total kjeldahl nitrogen (37, p.468 & 244).

f. Orthophosphate

Orthophosphate was determined by the method described by Jankovic, et al. (38). Fifty ml of sample were filtered through a 0.45-μ membrane filter and 10 ml of this filtrate were diluted to 100 ml with deionized water; 8 ml of mixed reagent were placed in a nessler tube and enough of the diluted filtrate was added to produce a total volume of 50 ml. Ten min were allowed for color development and the absorbance was read at 885 mμ using a spectrophotometer* equipped with a red-sensitive phototube and a red filter. The concentration of orthophosphate was determined from a calibration curve and was expressed in mg/l P. All glassware used in this determination was cleaned using standard laboratory procedures followed by a rinse with 1 + 1 hydrochloric acid.

g. Total Phosphorus

Total phosphorus was also determined by the method described by Jankovic, et al. (38). Ten ml of sample were placed in a 125-ml erlenmeyer flask, along with 2.0 ml 5N sulfuric acid and 1.0 g potassium persulfate, and approximately 30 ml deionized water and a few boiling beads were added and the dilution was boiled for 15 min.

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*Spectronic 20, a product of Bausch & Lomb, Inc., Rochester, NY.

After cooling, the digested sample was diluted to 100 ml (a total dilution of 10 times), and the phosphorus concentration was measured as previously outlined under the orthophosphate determination.

h. Chloride

The argentometric method was used (37, p.96). One ml of potassium chromate indicator solution was added to a 100-ml sample which was then titrated with 0.0141N silver nitrate titrant to a pinkish yellow end point. The volume of titrant was used to determine the concentration of chloride present in the sample.

i. Chemical Oxygen Demand

Chemical oxygen demand was determined using the procedure given in Standard Methods (37, p.495), except that the concentrated sulfuric acid-silver sulfate reagent was added to the sample before the flask was placed on the reflux condenser. Twenty ml of sample were added to a refluxing flask already containing 0.4 g mercuric sulfate and a few glass beads, and were followed by 10.0 ml of standard potassium dichromate and 30 ml of sulfuric acid-silver sulfate reagent. The mixture was refluxed for 2 hr, cooled and titrated with standard ferrous ammonium sulfate solution using ferroin indicator. Samples collected during the August 7 storm were analyzed using the alternate procedure for dilute samples (37, p.498) which employed reduced normality reagents. In the early part of the study samples were analyzed as collected; however, because of the widely varying quantities of sediment, which apparently contained a significant amount of organic

matter, beginning with the April 4 storm samples were centrifuged* at 2500 rpm for 20 min before analysis.

j. Total Organic Carbon

Total organic carbon was determined using a carbonaceous analyzer** (37, p.257). Inorganic carbon (and possibly some of the more volatile organic substances) was first removed by acidifying the sample to a pH of 2 or less with hydrochloric acid and bubbling carbon dioxide-free nitrogen gas through the acidified sample for at least 10 min. A 20-µl portion of the sample was injected into the instrument where organic matter was catalytically oxidized with pure oxygen at 900° C; the carbon dioxide formed was passed through an infrared analyzer and the resulting peak height was recorded on a strip-chart recorder. The injection was repeated at least 2 more times or until satisfactory agreement between peak heights had been obtained. A standard curve was prepared in the same manner using acetic acid and was used to determine the concentration of organic carbon in the sample.

k. pH

The pH was determined using a pH meter.#

2. Physical Group

a. Total Residue on Evaporation

Total residue was determined as described in Standard Methods (34, p.535 & 288), except that a 50 ml sample and a 50 ml preignited

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*A Model UV centrifuge was used; it was a product of the International Equipment Co., Needham Heights, MA.
**Beckman Carbonaceous Analyzer, a product of Beckman Instruments, Inc., Fullerton, CA.
#Zeromatic, a product of Beckman Instruments, Inc., Fullerton, CA.

(550° C) evaporating dish were used. The sample was evaporated on a steam bath, dried at 103° C in an oven overnight and weighed. The increase in weight was used to determine the total residue concentration.

b. Total Volatile Residue

Following the total residue determination, the sample was ignited at 550° C (37, p.536) in a muffle furnace* for 1 hr, cooled and weighed to determine the total volatile residue concentration.

c. Total Suspended Matter

Total suspended matter was determined by filtering an appropriate volume of sample (10 to 100 ml) through a predried and tared 0.45-μ membrane filter. The filter and retained solids were dried overnight at 103° C and the increase in weight was used to compute the concentration of total suspended matter.

d. Dissolved Matter

Dissolved matter was determined as the difference between the total residue on evaporation and the total suspended matter.

e. Turbidity

Turbidity was determined using a turbidimeter** which was a nephelometer and photometrically measured the amount of light reflected at right angles to the incident light beam by the turbidity-causing particles. This instrument was calibrated in candle turbidity units and was standardized with a standard turbidity rod supplied by the manufacturer.

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*Type 054-PT furnace, a product of Lindberg Hevi-Duty, Oconomowoc, WI.
**Model 1860 laboratory turbidimeter, a product of the Hach Chemical Company, Ames, IA.

f. Color

True color was determined (37, p.160) using samples which had been centrifuged* at 2500 rpm for 30 min. The centrifuged sample was compared against deionized water to assure that turbidity had been removed, and its color was determined using standards made from potassium chloroplatinate and cobaltous chloride. The pH of the centrifuged sample was also measured.

3. Bacteriological Characteristics

a. Total Coliforms

The total coliform group was measured by the multiple tube fermentation procedure (37, p.664) using the presumptive and confirmed tests. A series of dilutions was made and used to inoculate in triplicate fermentation tubes containing lauryl tryptose broth. The tubes were incubated** at 35 ± 0.5° C for 24 to 48 hr, and the positive tubes were used to determine the Most Probable Number (MPN)/100 ml.

b. Fecal Coliforms

Fecal coliform determinations were performed on all positive presumptive tubes in the total coliform test using EC medium fermentation tubes. The inoculated tubes within 30 min after planting were placed in a water bath# held at 44.5 ± 0.2° C and were incubated for 24 hr.

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*A Model UV centrifuge was used; it was a product of International Equipment Co., Needham Heights, MA.

**A Precision-Thelco Model 6 incubator was used; it was a product of the Precision Scientific Co., Chicago, IL.

#A Magni-Whirl water bath was used; it was a product of the Blue M Electric Co., Blue Island, IL.

The water level in the bath was kept sufficiently high to immerse the tubes to the upper level of the medium. Positive tubes were used to determine the MPN/100 ml.

c. Standard Plate Count

A plate was prepared for each dilution of each sample tested by the total coliform procedure using tryptone glucose extract agar and a 1-ml test volume. The plates were incubated* inverted at 35 $\pm$ 0.5° C for 24 hr, and the resulting colonies were counted with the aid of a Quebec colony counter. Only plates showing between 30 to 300 colonies were considered in determining the standard plate count which was expressed as the count/ml.

C. EXPERIMENTAL RESULTS

Runoff from 10 different storms was sampled during the 6-month period from February 4 to August 7, 1971. The sites sampled during each storm and the analyses performed varied considerably. This was necessary because construction was still in progress when sampling was started, and either equipment had not yet been installed at all sites, or time was not available to devote to extensive laboratory work because of other project needs. The reason for initiating sampling before the equipment had been completely developed and installed was twofold: Preliminary data were necessary to provide information on required modifications of the sampling system, and it was desirable to obtain at least some data over as long a period of time as possible. Chemical oxygen demand and total residue determinations were made on

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*A Precision-Thelco Model 6 incubator was used; it was a product of the Precision Scientific Co., Chicago, IL.

the samples collected from most storms. Other analyses varied from storm to storm.

The results of physical and chemical determinations are presented in Table III and bacteriological findings obtained from the storm of August 7 are given in Table IV. Appropriate precipitation data were summarized in Table II (p.54) and additional information on each event sampled is presented in the following pages. The automatic samples tabulated in Table III were numbered consecutively during a given storm event to correspond with the sections of the 2 sampler distributor troughs, and were as follows:

Sample No.	Period of Sampling
1 through 6	5-min each
7 & 8	15-min each
9 & 10	1-hr each
11 through 15	2-hr each
16 and larger	variable

Grab samples, which were occasionally taken, are identified with the prefix "G" and samples collected at the discharge of a pump are designated by the prefix "P". To simplify record-keeping and minimize confusion, the 24-hr clock system was used throughout the project.

1. Storm of February 4

Sampling began on February 4 at Site A using the prototype sampling unit. Modifications to the unit had not been made at that time and a temporary intake, with the intake line lying on the surface of the ground, was used. Slow, misting precipitation had begun on February 3 and continued on February 4. The rainfall sampled started about 1130 on February 4 and continued until 1400, with the sampling initiated manually at 1535 and extended until 1735 when the water level in the stream had receded to a depth insufficient to cover the intake. A total

TABLE III. CHEMICAL AND PHYSICAL CHARACTERISTICS OF STORMWATER RUNOFF

		Date	Feb 4									Feb 21							
Sample		Site	A									A							
		No.	1	2	3	4	5	6	7	8	9	1	2	3	4	5	9	11	12
Collection		Time	1535-1540	1540-1545	1545-1550	1550-1555	1555-1600	1600-1605	1605-1620	1620-1635	1635-1735	1445-1450	1450-1455	1455-1500	1500-1505	1505-1510	1800-1900	2000-2200	2200-2315
		Period, min	5	5	5	5	5	5	15	15	60	5	5	5	5	5	60	120	75
Parameter	Chemical	Total Alkalinity, mg/l as $CaCO_3$																	
		Total Hardness, mg/l as $CaCO_3$																	
		Ammonia Nitrogen, mg/l N																	
		Total Kjeldahl Nitrogen, mg/l N																	
		Organic Nitrogen, mg/l N																	
		Orthophosphate, mg/l P																	
		Total Phosphorus, mg/l P																	
		Chloride, mg/l																	
		Chemical Oxygen Demand, mg/l*	51.5	63.5	45.5	47.6	39.6	51.5	59.5	35.6	43.6	232	311	465	415	482			57.2
		Total Organic Carbon, mg/l																	
		pH	7.1	7.1	7.6	7.5	7.4	7.3	7.2	7.4	7.2	7.0	7.3	6.9	6.9	7.0	7.1	7.0	7.1
	Physical	Total Residue, mg/l																	
		Total Volatile Residue, mg/l																	
		Total Suspended Matter, mg/l	98	227			236		210	72		115	105	55					
		Dissolved Matter, mg/l																	
		Turbidity, turbidity units	170	170	170	170	150	160	160	55	130	150	130	80	100	40	130	130	50
		Color, color units																	

*Determined on samples as collected Feb 4-Mar 6 and centrifuged samples Apr 4-Aug 7.

		Date	Feb 21											Feb 22									Feb 23	Feb 24		Feb 25		* Feb 21
Sample		Site	B																									C
		No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	G**
Collection		Time	1415-1420	1420-1425	1425-1430	1430-1435	1435-1440	1440-1445	1445-1500	1500-1515	1515-1615	1615-1715	1715-1915	2300-0100	0100-0300	0300-0500	0500-0700	0700-0840	0840-1040	1040-1240	1240-1440	1440-1640	1640-1840	1840-0640	1840-0640	0640-1800	1800-0600	0915-1935	1935-0700	1840
		Period, min	5	5	5	5	5	5	15	15	60	60	120	120	120	120	120	100	120	120	120	120	120	720	720	680	720	620	685	---
Parameter	Chemical	Total Alkalinity, mg/l as $CaCO_3$																												
		Total Hardness, mg/l as $CaCO_3$																												
		Ammonia Nitrogen, mg/l N																												
		Total Kjeldahl Nitrogen, mg/l N																												
		Organic Nitrogen, mg/l N																												
		Orthophosphate, mg/l P																												
		Total Phosphorus, mg/l P																												
		Chloride, mg/l																												
		Chemical Oxygen Demand, mg/l#	61.5	30.8	38.5	30.8	42.3	42.3	92.4	65.4	34.6	38.5							30.6	15.3	15.3	30.6	15.3	7.6	15.3	7.6	0	0	5.7	63.5
		Total Organic Carbon, mg/l																												
		pH	7.8	7.9	7.9	7.8	7.6	7.6	7.5	7.5	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.5	7.3	7.2	7.2	7.3						7.4	7.4	7.0
	Physical	Total Residue, mg/l	394	370	414	404	362	370	545	424	270	238	270	238	196	188	190	196	298	284	296	332	302	290	326	304				
		Total Volatile Residue, mg/l	102	112	98	114	68	98	106	82	60	62	66	52		30	46	80	130	102	148	106	124	128	144	156				
		Total Suspended Matter, mg/l	100	70	80	55	130	190	280	125	195	50	100	65																
		Dissolved Matter, mg/l	294	300	334	349	232	180	265	299	75	208	170	173																
		Turbidity, turbidity units	60	38	50	50	55	60	75	65	50	50	37	35	34	28	25	26	27	24	24	45						13	12	180
		Color, color units																												

*Collected on Feb 26

**Grab sample from stream.

Determined on samples as collected Feb 4-Mar 6 and on centrifuged samples Apr 4-Aug 7.

TABLE III (Continued). CHEMICAL AND PHYSICAL CHARACTERISTICS OF STORMWATER RUNOFF

		Date	Mar 6											Apr 4													Apr 5			
Sample		Site	A			B		C						A			B													
		No.	1	2	3	1	2	1	2	3	4	5	1	2	3	4	1	2	3	4	5	7	8	11	12	13	14	15		
Collection		Time	1015-1215	1215-1415	1415-1500	1030-1230	1230-1430	1415-1500	1530-1630	1630-1830	1830-2030	2030-2230	1710-1715	1715-1720	1720-1725	1725-1730	1720-1725	1725-1730	1730-1735	1735-1740	1740-1745	1750-1805	1805-1820	2020-2220	2220-0020	0220-0420	0420-0620	0620-0820		
		Period, min	120	120	45	120	120	45	60	120	120	120	5	5	5	5	5	5	5	5	5	15	15	120	120	120	120	120		
Parameter	Chemical	Total Alkalinity, mg/l as $CaCO_3$																												
		Total Hardness, mg/l as $CaCO_3$																												
		Ammonia Nitrogen, mg/l N																												
		Total Kjeldahl Nitrogen, mg/l N																												
		Organic Nitrogen, mg/l N																												
		Orthophosphate, mg/l P																												
		Total Phosphorus, mg/l P																												
		Chloride, mg/l																												
		Chemical Oxygen Demand, mg/l*	43.6		19.8			27.8	35.7		15.9	9.9	60.6	30.8	55.3	135	59.9	30.0	41.2	41.2	39.2	13.1	20.6			7.5	1.9	6.4		
		Total Organic Carbon, mg/l																												
		pH											7.2	7.1	7.1	7.2	7.6	6.8	7.3	7.7	7.7	7.7	7.6	7.4	7.5	7.4	7.5	7.5		
	Physical	Total Residue, mg/l	398	416	368	310	302	442	410	408							264	240	230	224	228	252	252	190	200	236	248	270		
		Total Volatile Residue, mg/l	116	140	168	118	130	134	188	182							68	60	54	68	60	68	70	30	52	56	42	44		
		Total Suspended Matter, mg/l															4.0		8.0	0	18.0	16.0								
		Dissolved Matter, mg/l															260		222	224	210	236								
		Turbidity, turbidity units											85	80	55	90	25	24	25	26	25	25	24	12	9.0	6.0	5.0	10		
		Color, color units																												

*Determined on samples as collected Feb 4-Mar 6 and on centrifuged samples Apr 4-Aug 7.

		Date	Apr 4							Apr 6															
Sample		Site	C							B								C							
		No.	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	16	17	18	19	20	21*	22
Collection		Time	1740-1840	1840-1940	1940-2140	2140-2340	2340-0140	0140-0340	0340-0540	1815-0215	0215-0415	0415-0615	0615-0815	0815-1015	1015-1215	1215-1415	1415-1515	1515-0115*	0815-1015	1015-1215	1215-1415	1415-1615	1615-1815	1815-2015	2015-2215
		Period, min	60	60	120	120	120	120	120	480	120	120	120	120	120	120	60	600	120	120	120	120	120	120	120
Parameter	Chemical	Total Alkalinity, mg/l as $CaCO_3$																							
		Total Hardness, mg/l as $CaCO_3$																							
		Ammonia Nitrogen, mg/l N																							
		Total Kjeldahl Nitrogen, mg/l N																							
		Organic Nitrogen, mg/l N																							
		Orthophosphate, mg/l P																							
		Total Phosphorus, mg/l P																							
		Chloride, mg/l																							
		Chemical Oxygen Demand, mg/l**	74.9	63.7		39.2	29.9	29.9	33.6	39.4	84.0	7.4	103	55.3	36.2				34.0	24.5	37.2	160	138	42.6	31.9
		Total Organic Carbon, mg/l																							
		pH	8.3	7.9	7.3	7.1	7.2	7.2	7.2	7.5	7.1	7.5	7.2	7.2	6.9	7.4	7.6	7.7	7.2	7.6	7.5	7.6	7.4	7.3	7.4
	Physical	Total Residue, mg/l	400	414	386	346	354	348	354	308	300	258							344	422					
		Total Volatile Residue, mg/l	86	84	96	62	66	74	82	104	46	36							56	124					
		Total Suspended Matter, mg/l	138	110																					
		Dissolved Matter, mg/l	242	304																					
		Turbidity, turbidity units	90	90	65	60	55	50	34	3	27	13	64	60	40	20	9	7	33	14	50	170	190	70	60
		Color, color units																							

*Sampling continued to Apr 7.
**Determined on samples as collected Feb 4-Mar 6 and on centrifuged samples Apr 4-Aug 7.

TABLE III (Continued). CHEMICAL AND PHYSICAL CHARACTERISTICS OF STORMWATER RUNOFF

Parameter		Date	May 10									May 11				May 10										May 11			
		Sample: Site	B													C													
		Sample: No.	G*	P**	10	11	12	13	14	15	16	17	18	19	20	21	G*	P**	10	11	12	14	15	16	17	18	19	20	21
		Collection: Time	1400	1400-1405	0700-0800	0800-1000	1000-1200	1200-1400	1400-1600	1600-1800	1900-2100	2100-2300	2300-0100	0100-0300	0300-0500	0500-0700	1515	1515-1520	0715-0815	0815-1015	1015-1515	1515-1715	1715-1915	1915-2115	2115-2315	2315-0115	0115-0315	0315-0515	0515-0715
		Period, min	--	5	60	120	120	120	120	120	120	120	120	120	120	120	--	5	60	120	300	120	120	120	120	120	120	120	120
Chemical		Total Alkalinity, mg/l as $CaCO_3$																											
Chemical		Total Hardness, mg/l as $CaCO_3$																											
Chemical		Ammonia Nitrogen, mg/l N																											
Chemical		Total Kjeldahl Nitrogen, mg/l N	0.67	1.68	0.56												0.34	0.11	0.11										
Chemical		Organic Nitrogen, mg/l N																											
Chemical		Orthophosphate, mg/l P																											
Chemical		Total Phosphorus, mg/l P																											
Chemical		Chloride, mg/l																											
Chemical		Chemical Oxygen Demand, mg/l#	10.4	10.4	62.2	20.7	20.7	20.7		18.6							36.3	43.5	124	51.8	41.4	46.6	93.3						
Chemical		Total Organic Carbon, mg/l																											
Chemical		pH									7.4	7.7	7.5	7.7	7.7	7.8								7.4	7.4	7.5	7.6	7.6	7.6
Physical		Total Residue, mg/l			504		456	322											980	638	572	502							
Physical		Total Volatile Residue, mg/l																											
Physical		Total Suspended Matter, mg/l																											
Physical		Dissolved Matter, mg/l																											
Physical		Turbidity, turbidity units									45	20	13	13	13	13								85	80	65	45	40	39
Physical		Color, color units																											

*Grab sample from creek.
**Sample taken directly from pump discharge.
#Determined on samples as collected Feb 4-Mar 6 and on centrifuged samples Apr 4-Aug 7.

Parameter		Date	Jun 1															
		Sample: Site	B								C							
		Sample: No.	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
		Collection: Time	0545-0550	0550-0555	0555-0600	0600-0605	0605-0610	0610-0615	0615-0630	0630-0645	0505-0510	0510-0515	0515-0520	0520-0525	0525-0530	0530-0535	0535-0550	0550-0605
		Period, min	5	5	5	5	5	5	15	15	5	5	5	5	5	5	15	15
Chemical		Total Alkalinity, mg/l as $CaCO_3$	316	320	292	320	300	292	292	288	404	412	362	312	228	200	200	288
Chemical		Total Hardness, mg/l as $CaCO_3$	193	184	172	157	189	189	170	174	474	377	314	260	208	178	178	233
Chemical		Ammonia Nitrogen, mg/l N	0.38	0.14	0.66	0.88	0.72	1.02	0.92	0.68	0.16	0.70	1.28		1.30	2.08	0.96	1.06
Chemical		Total Kjeldahl Nitrogen, mg/l N	3.08	3.92	3.46	2.68	4.48	2.80	2.59	2.07	4.90	4.06	3.47	3.64	5.30	5.15	3.13	1.68
Chemical		Organic Nitrogen, mg/l N	2.70	3.78	2.80	1.80	3.76	1.78	1.67	1.39	4.74	3.36	2.19		4.00	3.07	2.17	0.62
Chemical		Orthophosphate, mg/l P																
Chemical		Total Phosphorus, mg/l P	0.10	0.10	0.17	0.10	0.12	0.18	0.05	0.05	0.20	0.10	0.65	0.95	0.95	0.70	0	0
Chemical		Chloride, mg/l		11.8	11.8	24.6		0	9.9	9.9	133	120	85.8	66.0	47.3	38.4	40.4	69.0
Chemical		Chemical Oxygen Demand, mg/l*	10.2	0	25.5	15.3	25.5	20.4		25.5	51.0	20.4	112	112	173	176	148	107
Chemical		Total Organic Carbon, mg/l		10.0	11.0						8.0	5.0	12.0	25.5	27.0	21.0	21.0	21.0
Chemical		pH	7.8	7.4	7.3	7.6	7.8	7.8	7.4	7.5	7.7	7.8	7.1	7.0	6.8	7.1	7.7	7.8
Physical		Total Residue, mg/l	384	368	360	344	316	392	286	276	812	766	692	572	538	470	512	438
Physical		Total Volatile Residue, mg/l	48	4		60	48	68	64	52	152	166	142	136	132	92	138	114
Physical		Total Suspended Matter, mg/l	108	120	77		120	160	50	48	31	33	44	59	75	88	54	23
Physical		Dissolved Matter, mg/l	276	2148	283		196	232	236	228	781	733	648	513	463	382	458	415
Physical		Turbidity, turbidity units	50	55	50	45	38	37	28	28	28	28	34	37	55	45	33	10
Physical		Color, color units **		10	15	15			20	30	15	5	25	50	70	60	55	38

*Determined on samples as collected Feb 4-Mar 6 and on centrifuged samples Apr 4-Aug 7.
**The pH of the centrifuged samples used for color determination varied from the pH of the corresponding raw water samples by -0.6 to +0.4 max.

TABLE III (Continued). CHEMICAL AND PHYSICAL CHARACTERISTICS OF STORMWATER RUNOFF

		Date	Jun 2																										Jun 3
		Sample: Site	A								B						C												
		No.	G*	P**	1	7	8	9	10	11	10	11	12	13	14	15	1	2	3	4	5	7	9	10	11	12	13	14	15
		Collection: Time	1450	1450-1455	1415-1420	1445-1500	1500-1515	1515-1615	1615-1715	1715-1835	1515-1615	1615-1815	1815-2015	2015-2215	2215-0015	0015-0215	1400-1405	1405-1410	1410-1415	1415-1420	1420-1425	1430-1445	1500-1600	1600-1700	1700-1900	1900-2100	2100-2300	2300-0100	0100-0300
		Period, min	--	5	5	15	15	60	60	60	60	120	120	120	120	120	5	5	5	5	5	15	60	60	120	120	120	120	120
Parameter	Chemical	Total Alkalinity, mg/l as $CaCO_3$			262	156	148	146	176	260	134	196	278	308	304	304	334	336	341	330			124	126	168	186	215	250	260
		Total Hardness, mg/l as $CaCO_3$	126	126	151	84	143	122	122	164	122	76	155	159	164	166	256	264	256	239	155	228	108	174	157	151	172	184	193
		Ammonia Nitrogen, mg/l N	0.74	0.90	0.64	0.52	0.52	0.58	0.58	0.40	0.96	0.74	0.58	0.38	0.52	0.80	1.06	1.00	0.78	1.00	1.46	0.58	0.46	0.52	0.46	0.90	0.64	0.58	0.40
		Total Kjeldahl Nitrogen, mg/l N	5.74	7.28	3.75	4.53	4.82	3.09	2.66	2.24	1.96	2.85	2.85	1.45		0	1.01	2.86	1.85	2.35	3.92	6.50				3.47			0.22
		Organic Nitrogen, mg/l N	5.00	6.38	3.11	4.01	4.30	2.51	2.08	1.84	1.00	2.11	2.27	1.07			0	1.86	1.07	1.35	2.46	5.92				2.57			
		Orthophosphate, mg/l P																											
		Total Phosphorus, mg/l P	1.72	1.70	0.45	1.63	1.20	0.30	0.10	0.05	0.12	0.05	0.08	0.05	0.05	0.05	0.02	0.02	0.05	0.05	0.25	0.85	0.55	0.40	0.20	0.12	0.12	0.10	0.05
		Chloride, mg/l	4.9	4.9	16.8	3.0	4.9	5.9	7.9	11.8	3.0	6.9	10.8	10.8	10.8	10.8	66.0	65.1	66.0	62.1	32.5	11.8	9.9	178	91.7	72.4	68.0	67.0	68.0
		Chemical Oxygen Demand, mg/l#	29.9	19.9	24.9	19.9	39.9	39.9	29.9	29.9	29.9	29.9	24.9	24.9	29.9		39.9	49.8	44.8	44.8	19.9	39.9	49.8	59.9	69.6	49.8	45.0		40.0
		Total Organic Carbon, mg/l		20.5	21.5	7.0	9.0	9.5	9.5	8.0	14.0	9.5	9.0	8.0	6.5	7.0	11.0	15.0	13.0	11.5	16.0	6.5	6.5	8.0	9.5	8.5	9.0	9.0	9.0
		pH	8.1	8.1	7.6	7.4	7.8	8.0	8.1	7.8	7.4	7.4	8.0	8.2	7.6	8.2	8.2	8.2	8.1	8.3	8.4	7.8	8.1	8.1	8.1	8.2	8.2	8.1	8.2
	Physical	Total Residue, mg/l	2082	2568	712	1636	1074	574	322	356	280	192	206	212	202	228	434	530	436	426	534	1870	550	808	528	450	402	396	382
		Total Volatile Residue, mg/l	216	246	118	198	130	130	108	2	42	32	30	38	44	60	114	150	120	138	106	360	70	158	136	118	104	100	124
		Total Suspended Matter, mg/l	1916	2336	514	1426	774	276	96	74	190	254	64	18	66	29			2	40	296	1650	415	280	194	130	68	64	46
		Dissolved Matter, mg/l	166	232	198	210	300	298	226	282	90		142	194	136	199			434	386	238	220	135	528	334	320	334	332	336
		Turbidity, turbidity units	23	15	75	36	65	145	65	45	60	36	22	13	12	12	12	7.0	5.8	23	75	40	90	85	85	80	65	50	40
		Color, color units##	140	140	40	180	140	90	70	40	70	65	35	10	1	1	25	30	30	30	30	35	100	70	90	70	50	45	40

*Grab sample from stream.
**Sample taken directly from pump discharge.
#Determined on samples as collected Feb 4-Mar 6 and on centrifuged samples Apr 4-Aug 7.
##The pH of the centrifuged samples used for color determination varied from the pH of the corresponding raw water samples by -0.7 to +0.4 max.

		Date	Jun 10														
		Sample: Site	A		B				C								
		No.	1	2	1	4	5	6	1	2	3	4	5	6	7	8	9
		Collection: Time	0945-0950	0950-1045	0933-0838	1008-1108	1108-1208	1208-1240	0920-0925	0925-0940	0940-0955	0955-1055	1055-1155	1155-1355	1355-1555	1555-1755	1755-1855
		Period, min	5	15	5	60	60	32	5	15	15	60	60	120	120	120	60
Parameter	Chemical	Total Alkalinity, mg/l as $CaCO_3$	324	304	302	284	248	218	446	420	406	318	230	234	302	320	330
		Total Hardness, mg/l as $CaCO_3$	140	172	147	136	122	126	377	365	354	281	231	283	312	333	338
		Ammonia Nitrogen, mg/l N	2.66	3.68	0.78	0.36	0.52	0.48	0	0	0			0.64	1.00	0.46	0.52
		Total Kjeldahl Nitrogen, mg/l N	9.52	7.84	3.22	7.50	9.06	6.50			0.62	1.56	1.01				
		Organic Nitrogen, mg/l N	6.86	4.16	2.44	7.14	8.54	6.02			0.62						
		Orthophosphate, mg/l P															
		Total Phosphorus, mg/l P	0.58	0.48	0.18	0.10	0.05	0.05	0.02	0.10	0.05	0.18	0.10	0.05	0.05	0.02	0.05
		Chloride, mg/l	19.7	19.7	12.8	17.8	14.8	13.8	161	171	175	113	76.9	134	168	186	193
		Chemical Oxygen Demand, mg/l*	167	124	19.1	33.4	76.5	47.8	52.6	0	0	76.6	95.7	38.2	19.1	28.7	28.7
		Total Organic Carbon, mg/l	31.5	28.5	22.5	18.5	15.5	16.0	9.0	14.5	10.5	27.5	31.5	18.0	14.0	14.0	15.0
		pH	7.9	7.9	8.1	7.0	7.9	7.9	7.9	7.9	7.9	7.8	7.8	7.9	7.9	7.9	7.9
	Physical	Total Residue, mg/l	634	510	488	342	266	258	620	760	782	672	488	640	716	774	798
		Total Volatile Residue mg/l	144	160	88	78	98	80	156	220	260	250	190	230	284	310	298
		Total Suspended Matter mg/l	266	120	294	140	46										
		Dissolved Matter, mg/l	368	390	194	202	220										
		Turbidity, turbidity units	86	76	47	46	35	32	10	43	37	40	40	22	13	9.7	11
		Color, color units**	120	140	50	50	50	70	10	5	5	50	70	45	45	45	45

*Determined on samples as collected Feb 4-Mar 6 and on centrifuged samples Apr 4-Aug 7.
**The pH of the centrifuged samples used for color determination varied from the pH of the corresponding raw water samples by -0.6 to +0.6 max.

TABLE III (Continued). CHEMICAL AND PHYSICAL CHARACTERISTICS OF STORMWATER RUNOFF

Date		Aug 7																										
Sample	Site	A	B												C													
	No.	G*	1	2	3	5	6	7	8	9	10	11	12	13	1	2	3	4	5	6	7	8	9	10	11	12	13
Collection	Time	1358-1413	1301-1306	1306-1311	1311-1316	1321-1326	1326-1331	1331-1346	1346-1401	1401-1501	1501-1601	1601-1801	1801-2001	2001-2201	1313-1318	1318-1323	1323-1328	1328-1333	1333-1338	1338-1343	1343-1358	1358-1413	1413-1513	1513-1613	1613-1813	1813-2013	2013-2213
	Period, min	15	5	5	5	5	5	15	15	60	60	120	120	120	5	5	5	5	5	5	15	15	60	60	120	120	120
Parameter — Chemical	Total Alkalinity, mg/l as $CaCO_3$	142	137	100		98	118	140	96	161	135	122	126	132	222		218		144	100	113	118	157	144	111		120
	Total Hardness, mg/l as $CaCO_3$	338	188	125		125	149	173	211	186	610	714	150	150	497	501	480	422	342	221	221	284	372	288	236	1201	125
	Ammonia Nitrogen, mg/l N					0.26	0.70	0.70	0.60	0.20	0.18	0	0		0.40	0.18	0.12	0.64	1.45	2.00	1.16	0.86	0.96	0.70	0.64	0.30	0.86
	Total Kjeldahl Nitrogen, mg/l N	1.68	0.78			5.60	2.46	1.62	3.58	1.01	1.34	3.02	1.68	0.45	1.68	0.56		0.67	3.02	5.04	3.42	3.08	0.90		269	17.92	11.20
	Organic Nitrogen, mg/l N					5.34	1.76	0.92	2.98	0.81	1.16	3.02	1.68		1.28	0.38		0.03	1.57	3.04	2.26	2.22			2.05	17.62	10.34
	Orthophosphate, mg/l P	0.20	0	0		0.10	0.15	0.32	0.30	0.40	0.60	0.40	0.20	0.40	0.45	0.30	0.15	0.55	2.5	1.10	0.45	0.32	0.20	1.11	0.55	0.32	0.10
	Total Phosphorus, mg/l P	0.30	0.30	0.15		0.32	0.30	0.40	0.30	0.30	0.20	0.20	0.30	0.20	0.30	2.20	0.45	1.40	2.30	2.80	1.00	0.55	0.90	0.40	0.30	0.30	0.32
	Chloride, mg/l	263	19.6			27.0	4.90	18.1	24.5	20.6	13.7	12.7	12.7	12.7	451	441	433	358	265	161	155	237	257	243	168	122	133
	Chemical Oxygen Demand, mg/l**	38.2	25.7			41.9	45.6	23.5	19.8	28.3	47.3	45.4	28.7	34.7	20.6	0.74	21.4	47.3	66.2	83.1	64.7	45.6	51.1	61.1	59.4	57.2	55.0
	Total Organic Carbon, mg/l	18.5	16.0	6.0		19.5	50.0	16.0	13.0	15.0	16.0	16.5	8.0	13.0	10.0	11.5	11.0	31.5	49.0	51.0	31.5	19.5	23.0	20.0	23.0	45.5	49.0
	pH		7.6	7.5	7.3	7.9	7.6	7.8	7.5	7.6	7.3	7.7	7.3	7.8	7.4	7.2	6.8	7.5	7.4	7.3	7.2	7.5	7.5	7.5	7.2	7.3	7.2
	Total Residue, mg/l	836	505	420		342	425	338	448	282	326	304			1264	1304	1260	972	960	706	664	756	1004	654	576	2250	830
	Total Volatile Residue, mg/l	278	180	360		106	105	176	184	132	120	104			464	512	490	410	286	252	258	244	250	126	214	2200	350
	Total Suspended Matter, mg/l															80	22	158		86	38	50	34	0			
	Dissolved Matter, mg/l															1224	1238	814		620	626	706	970	654			
	Physical — Turbidity, turbidity units		36	8.0	5.0	7.0	19	12	25	10	8.0	9.0	9.0	7.0	7.0	15	9.0	21	9.0	8.0	10	19	19	40	16	18	14
	Color, color units#	40	45	20		80	80	50	50	40	45	40	40	35	10	5	20	40	80	60	10	30	40	40	45		35

*Grab sample from ditch

**Determined on samples as collected Feb 4-Mar 6 and on centrifuged samples Apr 4-Aug 7.

#The pH of the centrifuged samples used for color determination varied from the pH of the corresponding raw water samples by -0.4 to +0.9 max.

TABLE IV. BACTERIOLOGICAL CHARACTERISTICS OF STORMWATER RUNOFF-
STORM OF AUGUST 7, 1971*

Site	Collection Time	Total Coliforms	Fecal Coliforms	Standard Plate Count	Comments
		MPN/100 ml		Count/ml	
B	1326	930,000	230,000	150,000	Runoff began 1250, peaked 1305, & receded; started to rise again 1330, peaked 1340 & receded (all times ± 3 min).
	1440	43,000	23,000	81,000	
	1530	43,000	43,000	99,000	
C	1305	<300	<300	--	Runoff began 1310, peaked 1340 & began to recede (all times ± 3 min).
	1310	21,000	4,300	46,000	
	1312	43,000	43,000	--	
	1340	230,000	43,000	310,000	
	1400	43,000	43,000	190,000	
	1430	23,000	9,300	120,000	
	1525	2,100	24,000	300,000	

*Rainfall began approximately 1230.

of 9 samples were collected; they were highly turbid and apparently carried a great deal of sediment eroded from a bank just upstream from the sampling station. The sediment problem at Site A was not corrected until May 10, when the city at the author's suggestion placed broken concrete pavement against the bank of the drainage ditch to minimize erosion.

2. Storm of February 21

The sampler at Site B had been installed on February 18, and wire intake screens had been placed at both Stations A and B on February 20. Rock dams had also been constructed at both sites to provide a small pool for the intake to draw water from at low flows. The intake line at Site A had been buried.

Rainfall was observed to begin about 1250 and both Stations B and A were started manually at 1415 and at 1445, respectively. The interval between the beginning of precipitation and the start of sampling was required to allow enough time for runoff to increase to a depth sufficient to cover the pump intakes. Runoff was increasing at both sites at the time the pumps were started. When the stations were visited at about 1800, the sampling lines at Site A were found to be clogged with sediment and the intake fouled with trash. The timing motor driving Distributor 1 had stopped, apparently because a microswitch had been short-circuited by moisture. The lines and intake were cleared and the pump restarted. The pump at Site B had also stopped and the lines were clogged with sediment. Screw clamps which were used at that time for flow control were removed, the lines were flushed and the pump restarted. The screw clamps were left off the lines and the collection bottles were allowed to overflow.

Sampling continued at Site A until 2315 when the pump became inoperable because sediment suspended in its housing settled out and jammed the gears when the pump was stopped to allow backflushing of the intake line. Sampling at Site B was continued for about 6 days in order to obtain background information on the stream characteristics; 12-hr composite samples were collected during this period. A grab sample was also taken at Site C.

3. Storm of March 6

The sampler at Site C and prototype float switches at Sites A and C were installed on March 5, and sampling at all 3 locations was first undertaken on March 6. A number of problems developed, however; the float switches, which were mounted in metal 5-gal (18.9-l) solvent cans, were washed loose from their anchorage (they were recovered); and children pulled the intake from the water at Site C causing the pump to lose its prime and broke the intake tubing at Site B.

4. Storm of April 4

Runoff from falling, melting snow was sampled at all 3 sites on April 4. The float switches had been repaired and reinstalled at all sites, latching relays were provided for each sampler, and the intakes had been rebuilt and reanchored. Beginning with this storm, COD samples were centrifuged to overcome the variability introduced by eroded sediment.

5. Runoff of April 6

Warm temperatures caused accumulated snow to melt, and the resulting runoff was sampled. This was actually a continuation of the previous sampling event.

6. Storm of May 10

Construction of the stilling wells for the flow recorders began on April 7, and water level recorders were installed at Sites C and B on April 26. Staff gages were added to Sites B and C on April 28, and to Site A on May 8. As previously mentioned, rip rap was placed by the city at Site A on that date to act as an erosion barrier. The samplers were started manually at 0700 at Station B and 0715 at Station C; grab samples were also taken at both locations for comparison with results obtained using the automatic samplers. A check of the samplers at about 1030 revealed that a city work crew repairing a driveway adjacent to Site B had shoveled a considerable quantity of earth into the stream on top of the stilling well intakes and just upstream from the sampler intake. Examination of the flow record indicated that this occurred at about 1000. It was necessary to manually shovel a large portion of the earth from the stream to uncover the siphon inlet.

7. Storm of June 1

The water level recorder was installed at Site A on May 17 and on May 19 the pump intake was moved about 6 ft downstream to a more favorable location; the control at Site B was also rebuilt. On May 20, the float switch at Site C was found to have been severely vandalized and manual operation was instituted until the improved design switches had been installed. Rainfall began on June 1 about 0400 and continued until 0455; sampling was started manually at 0505 at Site C and at 0545 at Site B and continued for 1 hr at both locations. No runoff occurred at Site A.

8. Storm of June 2

Rainfall began at about 1405 and continued until 1700. The sampler at Site C was started manually at 1400 and at Site A at 1415; the unit at Site B had a pump malfunction and did not become operational until 1522. Sampling at Site A continued until 1835 on June 1, while at Site B and C the samplers were operated until 0215 and 0300, respectively, on June 3.

9. Storm of June 10

Precipitation began at 0830 and continued until about 1200. Site C was started manually at 0920, Site B at 0933 and Site A at 0945 (runoff was just beginning then at Site A and lasted until 1045). An oil slick was noted at Site C at 1100, and the city work crew again shoveled dirt into the stream on top of the siphon intakes at Site B necessitating cleaning.

10. Storm of July 9

A heavy downpour occurred on that date and damaged the sampling installations. Rain began falling at 2000 and continued until about 2155 with a total rainfall during the period of 1.40 in. (3.54 cm). The sampler at Site C was started manually at 2000, and the author drove to Site B and then to Site A to start these stations but was unable to do so because of a general power failure affecting at least that portion of the city. Upon returning to Site C a short time later, it was found that power had been restored at that location and the pump on the sampler had jammed and been damaged. This was apparently caused by sediment in the sample stream settling out inside the pump body when the pump stopped; the gears were jammed when the pump attempted to restart as power was restored. Other damage included loss

of the float switch containers and the inlets of the stilling well siphons, with resulting loss of flow records.

Following this storm, an extensive equipment modification program was undertaken, with construction beginning on July 17 and extending to August 1. New inlets for the siphons and samplers were designed, constructed and anchored in concrete; larger siphons and modified air chambers were provided, together with an improved method of priming; a new float switch was designed and installed inside the stilling well; and flow regulators were provided for each sampler.

11. Storm of August 7

Precipitation began at 1230 and terminated at 1310. All samplers started automatically and the lag time between the start of runoff and the start of automatic sampling was observed to be about 30 sec at Site C; this was again verified on August 11. Several grab samples were collected during the August 7 event of Sites B and C for bacteriological characterization and the results are presented in Table IV.

VI. DISCUSSION

An automatic stormwater runoff sampling and flow recording system was developed and successfully evaluated in the field. A study of the quality of runoff from a small urban area was initiated using 3 test watersheds in Rolla, and preliminary correlations with local environmental factors, including time since the beginning of runoff, antecedent dry period, average rainfall intensity and basin slope, were made.

A. SAMPLING AND FLOW RECORDING SYSTEM

The sampling system developed in this study furnished a positive, flexible and automatic means of sampling urban stormwater runoff. The system was capable of examining the stream base flow, sampling the first flush-off intensively and monitoring the runoff for an extended period of time. Sampling intervals could be varied by changing either or both the spacing of the divisions in the sampler troughs or the speed of the threaded carrier shafts, and the samples collected could be examined either individually or as physical or mathematical time- or flow-weighted composites.

Problems were encountered with the sampler during the study, especially with the pump used, but most were successfully resolved. The pump had been chosen primarily because of its low cost, and was found to be unsatisfactory. The pump was not self-priming and required a check valve in the intake line in order to maintain prime and enable automatic operation. The valve, however, was subject to wear and leakage caused by grit accumulations on its seat, and freezing of the water maintained in the lines during cold weather posed the probability of damage to the pump, intake lines and check valve. In addition, a gear-type pump was not suited for pumping water containing large amounts

of sediment and grit, as stormwater runoff did. A loss of pump efficiency developed when the plastic gear in the pump wore excessively, and grit caught between the teeth of the gears when the pump was stopped temporarily during a sampling run caused the pump to bind and fail to restart. It was then necessary to disassemble the pump and clean it before it could be started again, resulting in a loss of samples. Grit in the water also caused the seals at the pump shaft to wear and damage to these seals permitted air to enter the pump, causing loss of prime and cessation of pumping. These problems could have been solved by using a more appropriate pump, however, economic restrictions precluded this.

Another problem involved anchoring of the intake lines and float switches. Several methods were tried and the most satisfactory was found to be the use of 0.50-in. (1.3-cm) galvanized pipe and fittings to construct an intake device which was anchored to the stream bed using a cast-in-place concrete block. The problem with the float switches was solved by moving them to the stilling well, which provided adequate protection from both vandals and high flows.

The flow recording system, as finally developed, worked well. The water level in the stilling well and the recorder responded rapidly to changing levels in the stream without any apparent lag or clogging of the stilling well siphons. Initially, garden hose was used for the siphon lines but was not satisfactory. Its small diameter was conducive to clogging and did not permit a great enough flow to allow the water level in the stilling well to track closely the level in the stream. The hose maintained its circular cross section adequately during the cooler spring weather when it was installed, but softened and collapsed

under the negative pressure in the siphon during the warmer summer weather. All these problems were solved by installing larger diameter, more rigid plastic pipe. Air leaks in the siphons also presented a problem, primarily in the fittings and joints in the pipe, and a silicone rubber compound was used to seal each joint.

Measurement of stream velocity under high flow conditions was difficult at Sites A and B, with the greatest difficulty encountered at Site B due to the narrow channel and steep banks. A footbridge, constructed to facilitate this task, washed out on two different occasions before it could be satisfactorily anchored. The most serious problem with flow measurement, however, involved shifting controls in the stream at Sites A and B. The rock dam control section constructed at Site B proved to be unstable over a period of time due to erosion and debris accumulation, and although stable, the concrete cylinders used at Site A suffered from sediment deposition immediately upstream altering the control characteristics. There was no problem at Site C, where a stable control section was formed by the flat top of a concrete sewer passing under the stream. A better procedure at both Sites A and B would have been to construct a Parshall flume or other free-flowing cross section of concrete, which if properly designed, would have provided a stable, self-cleaning cross section; however, time and financial considerations precluded this from being done.

Precipitation data for the project was obtained from the weather station on the UMR campus and this created problems in that it was necessary to depend on others to operate and service the equipment. (Data from the storm of April 4 were not available because the recorder had not been serviced.) Ideally, each watershed should have been

provided with its own recording raingage and auxiliary standard gages to provide complete information on precipitation quantities and patterns. The UMR weather station was located centrally to the 3 basins, and since the total area involved was comparatively small and compact in configuration, the data obtained from the single gage should be representative of all 3 basins. Further studies should investigate the advisability of using additional gages.

B. QUALITY OF STORMWATER RUNOFF

Average stormwater runoff characteristics for each site and for all 3 sites are presented in Table V, together with the number of samples represented by each value. Arithmetic averages are given rather than flow- or time-proportional averages. Flow-proportional values could not be computed because flow data were not available for all sites and all storms, and have the disadvantage of giving equal weight to values obtained for all parts of the runoff. Time-proportional values could have been computed, but would have tended to mask the first flush-off effect even more than the arithmetic averages.

The lowest average concentrations for most characteristics were determined at Site B. This is of particular interest because a considerable portion of the runoff for this site first passed through a large pond (Frisco Pond) located on the watershed. Further investigation should be undertaken to determine if in fact the values resulted from the presence of the pond on the watershed, and evaluate the feasibility of utilizing small lakes or ponds for treatment of urban stormwater runoff.

TABLE V. AVERAGE CHARACTERISTICS OF STORMWATER RUNOFF

Parameter	Site							
	A		B		C		All	
	No.+	Avg	No.+	Avg	No.+	Avg	No.+	Avg
Total Alkalinity, mg/l as $CaCO_3$	8	210	29	220	38	251	75	234
Total Hardness, mg/l as $CaCO_3$	8	137	29	196	56	229	93	211
Ammonia Nitrogen, mg/l N	8	1.20	26	0.54	40	0.76	74	0.73
Total Kjeldahl Nitrogen, mg/l N	8	4.81	19	3.00	31	3.45	79	3.39
Organic Nitrogen, mg/l N	11	4.02	24	2.83	25	3.07	58	3.49
Orthophosphate, mg/l P*	--	--	11	0.26	13	0.55	24	0.42
Total Phosphorus, mg/l P	8	0.60	31	0.15	39	0.52	78	0.38
Chloride, mg/l	8	11.21	28	12.38	56	112	92	72.8
Chemical Oxygen Demand, mg/l#	12	50.0	68	31.3	65	55.6	145	43.1
Total Organic Carbon, mg/l	8	15.6	23	14.6	43	18.7	74	17.1
pH	29	6.9-8.1	79	6.8-8.2	63	6.8-8.4	171	6.8-8.4
Total Residue, mg/l	11	636	70	313	59	689	140	497
Total Volatile Residue, mg/l	11	128	66	86.7	58	213	135	144
Total Suspended Matter, mg/l	16	292	33	99.1	29	149	78	163
Dissolved Matter, mg/l	8	284	32	219	29	398	69	303
Turbidity,turbidity units	29	100	79	28	63	45	171	45
Color, color units	8	100	26	39	30	47	76	46
Total Coliforms, MPN/100 ml*	--	--	3	338,700	6	120,700	9	193,300
Fecal Coliforms, MPN/100 ml*	--	--	3	98,700	6	166,600	9	143,900
Standard Plate Count, count/ml*	--	--	3	8,400	6	33,900	9	25,300

*Represents data obtained from a single storm.
#Reflects centrifuged samples only.
+No. of samples averaged.

Flow-proportional averages were also developed for several characteristics using data obtained at Site C during the storm of August 7, 1971, and are presented in Table VI together with the corresponding arithmetic averages. The characteristics used were selected because values were available for all samples collected during the storm. The development of the weighting factors used in computing the flow-proportional averages is shown in Table VII. Flow-proportional values are more representative of the total quantity of a constituent present in the runoff than are arithmetic averages, but do not reflect as well peak concentrations present during the early stages of the runoff which may be significant in stormwater runoff management. Although arithmetic averaging gave equal weighting to each sample, flow-proportional averaging gave greater emphasis to samples No. 7 through 11 (Table VII) collected in the period when the largest portion of runoff occurred. Arithmetic averages were higher for total phosphorus, chloride, total and volatile residue, but were lower for ammonia nitrogen and chemical oxygen demand.

The average runoff characteristics are compared in Table VIII with appropriate water quality criteria and effluent guidelines. Runoff from the 3 watersheds studied discharges through Burgher Branch and Love Creek to Dry Fork Creek and then to Meramec River. Both streams are located in the Meramec River Basin (40) and are primarily used for recreation and agricultural use; in addition, Meramec River serves as a source of water supply for the City of Kirkwood (42). It should be mentioned that the criteria presented in Table VIII

TABLE VI. COMPARISON OF ARITHMETIC AND FLOW-PROPORTIONAL AVERAGE VALUES FOR SELECTED PARAMETERS-STORM OF AUGUST 7, 1971

Parameter	No.*	Arithmetic Avg $\bar{X}$	Mathematical Flow-Proportional Avg $\bar{F}$	% Difference $\frac{\bar{X} - \bar{F}}{\bar{X}} \times 100$
Ammonia Nitrogen, mg/l N	13	0.82	0.86	- 4.9
Total Phosphorus, mg/l		1.02	0.91	+ 10.8
Chloride, mg/l		268	235	+ 12.3
Chemical Oxygen Demand, mg/l		48.7	53.4	- 9.7
Total Organic Carbon, mg/l		28.8	28.0	+ 2.8
Total Residue, mg/l		1015	932	+ 8.2
Total Volatile Residue, mg/l		466	388	+ 16.7

*No. of samples averaged.

TABLE VII. DEVELOPMENT OF FLOW-PROPORTIONAL WEIGHTING FACTORS-SITE C, STORM OF AUGUST 7, 1971

Sample			Gage	Discharge			Weighting Factor
No.	Collection Time	Interval sec	Height ft*	Point** cfs#	Avg cfs#	Total cu ft##	
1	1313 1318	300	3.78 3.98	0.20 2.70	0.97	294	0.00883
2	1318 1323	300	3.98 4.10	2.70 4.70	3.70	1110	0.0333
3	1323 1328	300	4.10 4.13	4.70 5.20	4.95	1485	0.0445
4	1328 1333	300	4.13 4.18	5.20 7.40	6.30	1890	0.0567
5	1333 1338	300	4.18 4.13	7.40 5.20	6.30	1890	0.0567
6	1338 1343	300	4.13 4.10	5.20 4.70	4.95	1485	0.0445
7	1343 1358	900	4.10 4.07	4.70 4.00	4.35	3920	0.1174
8	1358 1413	900	4.07 4.03	4.00 3.30	3.65	3280	0.0985
9	1413 1513	3600	4.03 3.86	3.30 1.00	2.15	7750	0.2320
10	1513 1613	3600	3.86 3.84	1.00 0.70	0.85	3060	0.0918
11	1613 1813	7200	3.84 3.80	0.70 0.35	0.525	3780	0.1132
12	1813 2013	7200	3.80 3.78	0.35 0.20	0.275	1980	0.0594
13	2013 2213	7200	3.78 3.78	0.20 0.20	0.20	1440	0.0433
Total Values	1313 2213	32,400				33,364	1.0001

*To convert to m,multiply by 0.3048.
**Determined from rating curve (Figure 9) on basis of gage height.
#To convert to cu m/min, multiply by 1.7.
##To convert to cu m, multiply by 0.028.

TABLE VIII. COMPARISON WITH WATER QUALITY CRITERIA AND EFFLUENT GUIDELINES

Parameter	This Study	Water Quality Criteria					Effluent Guidelines
	Avg	Recreation (Primary Contact)	Public Water Supplies*	Fish, other Aquatic & Wildlife	Agri-cultural (Farmstead)	Meramec River Basin	Other Streams**
Total Alkalinity, mg/l as $CaCO_3$	234		30-500	>20			
Total Hardness, mg/l as $CaCO_3$	211		<300-500				2.0+
Ammonia Nitrogen, mg/l N	0.73		0.5				
Total Phosphorus, mg/l P	0.38			<0.1			
Chloride, mg/l	72.80		250				
Chemical Oxygen Demand, mg/l	43						100
pH	6.8-8.4	6.5-8.3	6.0-8.5	6.0-9.0	6.0-8.5	7.0-8.5	6.5-9.0
Dissolved Matter, mg/l	497		500		500		500++
Turbidity, turbidity units	50			<10 or 50#	substan-tially free		
Color, color units	46		75	##			
Total Coliform, MPN/100 ml	193,000		10,000				
Fecal Coliform, MPN/100 ml	143,900	200***	2,000			200###	
Reference	Table V	39				40	41

*Permissible criteria.
**Missouri streams other than the Missouri and Mississippi Rivers, Wild and Scenic Rivers and losing streams.
***Based on min of 5 samples over a 30-day period; 10% of such samples not to exceed 400/100 ml; max of 4,000/100 ml for general recreational use.
#Cold water streams: 10; warm water streams: 50.
##At least 10% of incident light must reach level where growth is to occur.
###MPN or MF count; not more than 10% of total samples during any 30-day period to exceed 400/100 ml.
+Or 0.10 of toxic level at prevailing pH value, if less.
++Allowable increase above that present in raw water supply.

represent characteristics for which values were given and do not reflect all criteria discussed in the appropriate publications (39) (40).

The quality of runoff established in this study for a small urban area is compared with values obtained by other investigators in large metropolitan areas in Table IX. Ammonia and organic nitrogen, chloride, pH, total and volatile residue and color were within the range of values reported by previous investigators. Dissolved matter, hardness and alkalinity were higher, probably because of groundwater contribution to the runoff sampled in an area underlain by limestone. Total phosphorus, chemical oxygen demand, suspended matter and turbidity were generally lower than the values reported for other areas. The lower concentrations for suspended matter and turbidity may perhaps be attributed to lower average watershed slopes in the Rolla area, while the lower total phosphorus and chemical oxygen demand values were probably related to other environmental factors. Further investigation is, however, necessary before specific conclusions may be drawn.

In an attempt to provide an insight into the effect of environmental factors on runoff quality, the data were examined with respect to time since the beginning of runoff, antecedent dry period, average rainfall intensity and basin slope. Selected characteristics were plotted as a function of time for Sites B and C and for the storm of August 7, 1971, and are presented in Figure 10. Runoff did not occur on that date at Site A. This storm was chosen because the best flow data and most complete analyses were available for it. The first flush-off effect is shown in Figure 10, except for chloride, total phosphorus and turbidity at Site B; chemical oxygen demand and total

TABLE IX. COMPARISON OF STORMWATER RUNOFF CHARACTERISTICS

Parameter	This Study		Previous Studies*			
	Range**	Avg	Avg	Avg	Range#	Avg
Total Alkalinity, mg/l as $CaCO_3$	220-251	234	59			
Total Hardness, mg/l as $CaCO_3$	137-229	211	78			
Ammonia Nitrogen, mg/l N	0.54-1.2	0.73	0.6	1.0		
Total Kjeldahl Nitrogen, mg/l N	3.0-4.8	3.49				
Organic Nitrogen, mg/l N	2.8-3.6	3.0	1.7	1.0	0-5.32	
Orthophosphate, mg/l P	0.26-0.55	0.42				
Total Phosphorus, mg/l P	0.15-0.60	0.38	1.1	5,000		1.3
Chloride, mg/l	12.4-112	73	12		2-46	
Chemical Oxygen Demand, mg/l	31.0-55.9	43.1	111		12-128	335
Total Organic Carbon, mg/l	14.6-18.7	17.1				
pH	6.8-8.4	6.8-8.4	7.5		6.8-8.4	6.5
Total Residue, mg/l	313-689	497	227		199-2,242	2,166
Total Volatile Residue, mg/l	86.7-213	144	163			302
Total Suspended Matter, mg/l	99.1-292	163		2,080	84-2,052	1,697
Dissolved Matter, mg/l	219-398	303			89-400	
Turbidity, turbidity units	29-100	45	170			600
Color, color units	39-100	45	81			310
Total Coliform, MPN/100 ml x 10^3	120.7-338.67	193.3	460		##	
Fecal Coliform, MPN/100 ml x 10^3	98.6-166.6	143.9	76		+	
Standard Plate Count, Count/ml x 10^3	8.44-33.9	25.3				
Location of Study	Rolla		Cincinnati	Ann Arbor	Tulsa	Washington
Reference	N/A		7,22	25	8	29

*Using automatic sampling equipment.
**Range of avg values for 3 sites.
#Range of avg values for 15 sites.
##The samples tested for total coliform had MPN/100 ml x 10^3 values: 10% > 1,140, 50% > 57, 90% > 2.1.
+The samples tested for fecal coliform had MPN/100 ml x 10^3 values: 10% > 30, 50% > 0.3, 90% > 0.002.

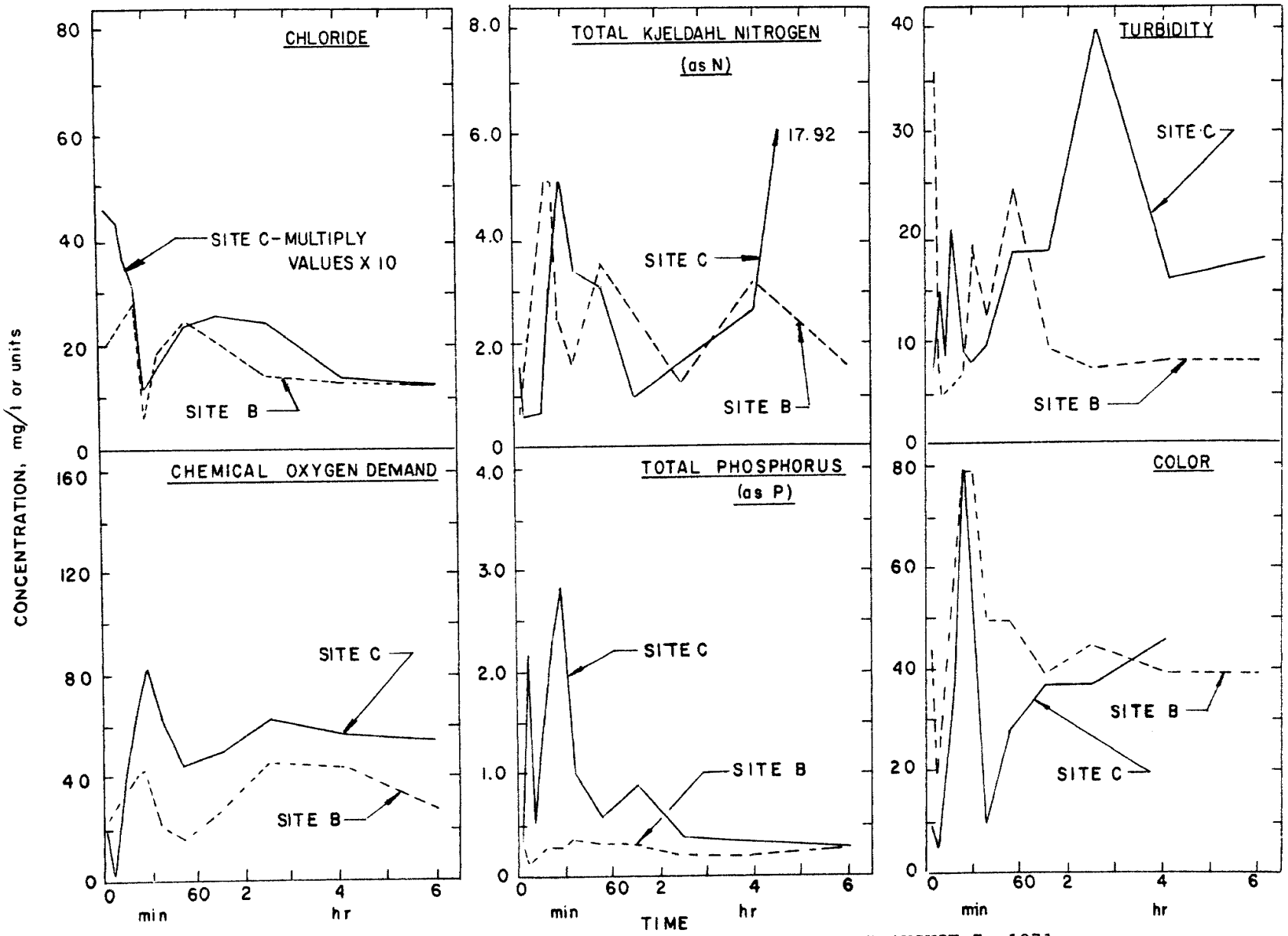

FIGURE 10. EFFECT OF TIME ON RUNOFF QUALITY-STORM OF AUGUST 7, 1971

kjeldahl nitrogen at Site C, and color at both sites showed an initial decrease prior to increasing with time.

The effect of the antecedent dry period (Table II, p.54) is shown in Figure 11. Data for Site C were used, as they were more numerous. Because of the variation in the duration of the runoff from different storms, average values for the initial 1-hr period were used for purposes of comparison. This may have introduced a certain amount of error since peak values for certain constituents might not have occurred until later in the runoff period. The concentration of chloride and total phosphorus increased with the length of the antecedent dry period, while total and volatile residue first decreased and then increased. A definite pattern was not established for chemical oxygen demand and total kjeldahl nitrogen which exhibited essentially the same response to antecedent precipitation.

Selected characteristics were evaluated with respect to the average intensity of rainfall (Table II) using average data for each storm at Site C, and the results are presented in Figure 12. Definite trends could not be established, although chemical oxygen demand appeared to decrease with an increase in the average intensity of rainfall and total residue tended to increase. The larger volume of water available to dilute a relatively fixed quantity of chemical demand-causing constituents and the greater transport energy resulting from higher runoff rates from the more intense storms could account for the trends observed.

The effect of average basin slope on runoff quality is depicted in Figure 13 using average concentration values. Basin slope was

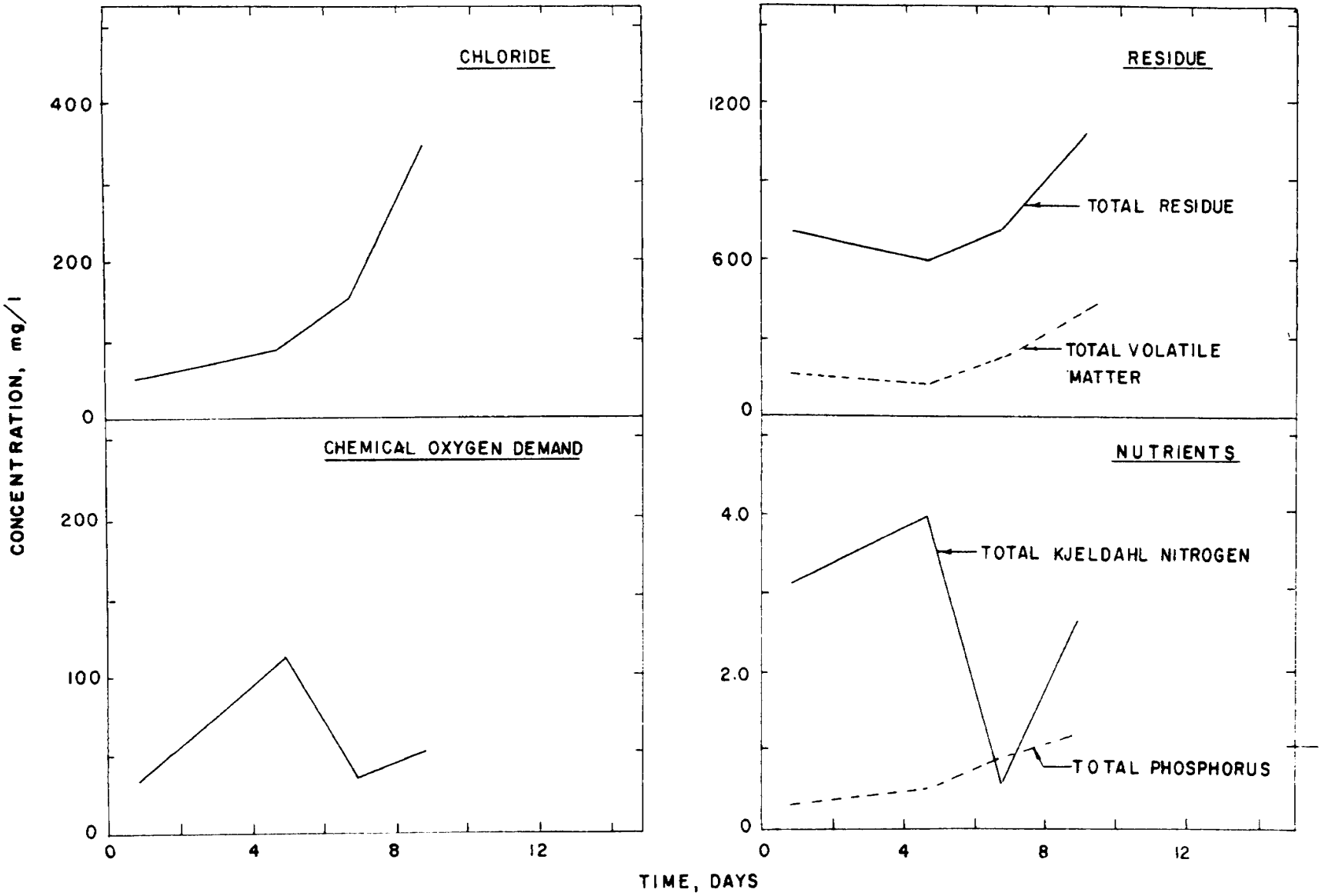

FIGURE 11. EFFECT OF ANTECEDENT DRY PERIOD-SITE C

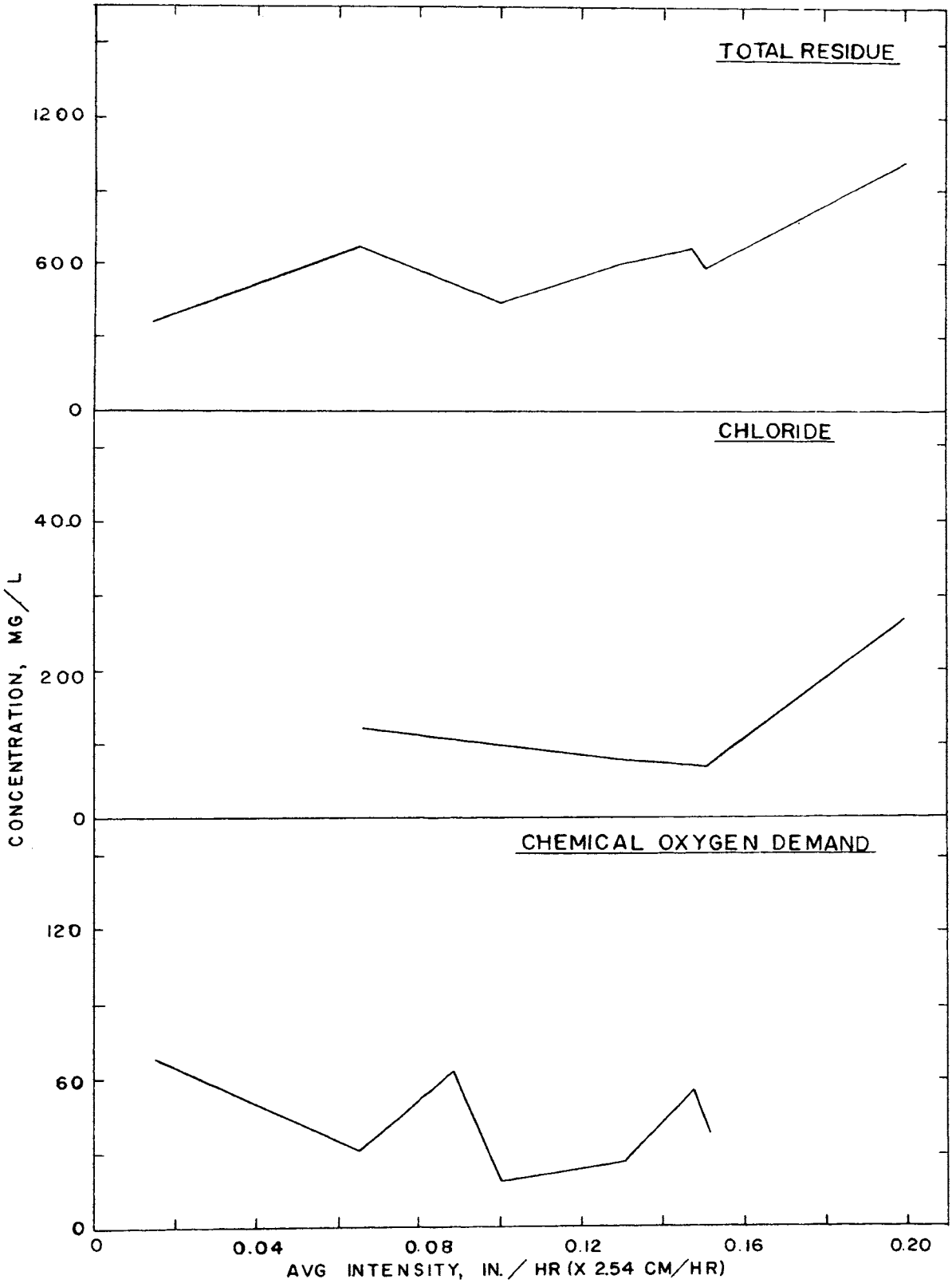

FIGURE 12. EFFECT OF PRECIPITATION INTENSITY-SITE C

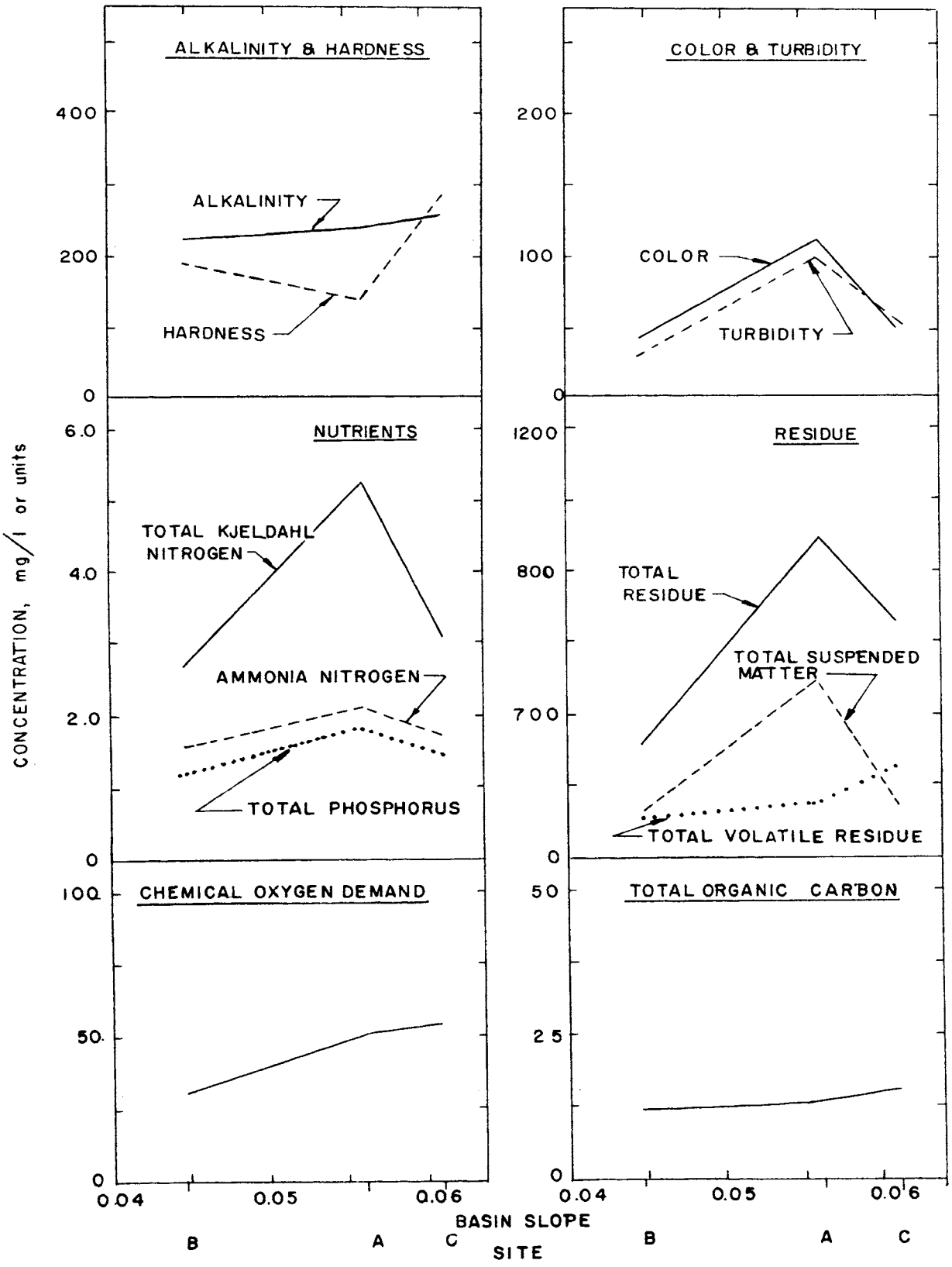

FIGURE 13. EFFECT OF BASIN SLOPE

determined (43, p.47) by measuring the length of contour lines within the watershed on a topographic map (50-ft contour intervals were used), multiplying by the contour interval (50 ft) and dividing by the area. Although the presence of Frisco Pond on Watershed B may have interfered in some instances, some patterns were established. Total and volatile residue, alkalinity, chemical oxygen demand and total organic carbon appeared to increase with increasing average basin slope; the discrepency with total residue at Site A was attributed to excessive bank erosion at that location. It was difficult to discern the effect of basin slope on the other characteristics which could have been affected to a greater degree by the presence of Frisco Pond on Watershed B.

VII. CONCLUSIONS

On the basis of the findings of this study, the following conclusions may be drawn.

1. The sampling and flow recording system developed in this investigation, when used in conjunction with adequate stream controls and properly maintained, provided an effective means for the qualitative and quantitative evaluation of urban stormwater runoff.
2. The system was capable of automatic operation; however, the physical presence of the investigator during each sampling event was essential because of the wide range of unpredictable situations under field conditions.
3. The quality of stormwater runoff from a small urban Missouri area was found to be comparable to the quality of runoff from larger metropolitan areas as reported in the literature.
4. The time since the beginning of the runoff event, the length of the antecedent dry period, the average intensity of precipitation and the basin slope were found to have an effect on runoff quality.

VIII. RECOMMENDATIONS FOR FURTHER RESEARCH

On the basis of the experience obtained during this study, the following areas of further research are recommended.

1. A long-range sampling program should be undertaken at the established sampling sites in order to determine the effect of seasonal variations.
2. A study should be made of the origin and movement of runoff in the watershed, and the effect of land use activities and wash-off of applied materials on runoff quality.
3. A study of the applicability of existing mathematical models, or if necessary, the development of new models for the predictions of runoff quality and quantity from a small urban area should be undertaken.
4. An investigation of the possibility of utilizing scenic or recreational lakes in the urban area for the treatment of stormwater runoff should be conducted.
5. An evaluation should be made of the effect urban stormwater runoff has on the receiving streams.
6. An investigation should be conducted of the sampler intake configuration and orientation necessary for obtaining representative samples under varying flow conditions.

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VITA

William Clark Ford was born on May 4, 1942, in Gainesville, FL. He received his primary education in Mexico and Centralia, MO, Houston, TX and Decatur, IL, and his secondary education in Decatur, IL. He received a Bachelor of Science Degree in Civil Engineering from the University of Missouri-Rolla in May 1966.

He worked as a sanitary engineer for the State of Illinois in the Bureau of Public Water Supplies from June 1966 to March 1967. He received a direct commission as an officer in the US Army in March 1967, and served as an environmental engineer assigned to the First US Army Medical Laboratory, Fort George G. Meade, MD, until May 1970.

He was enrolled as a graduate student in civil engineering at the University of Missouri-Rolla, from June 1970 to November 1971, and during this period he held an EPA Water Quality Traineeship. He is a registered professional engineer in the State of Missouri, and is a member of Chi Epsilon Civil Engineering Honorary Fraternity and an associate member of the Society of the Sigma Xi.

He was married to Sara Elizabeth Baker on June 11, 1966, and they have two daughters, Susan Elizabeth and Kristin Kimberly.